KNOWING THE WEATHER

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KNOWING THE WEATHER

by

T. MORRIS LONGSTRETH

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To

MEMORIES OF BALSAMS COTTAGE

and

RALPH WARNER HARBISON

HELEN HARRIS HARBISON

FRIENDS IN ALL WEATHERS

Forecast

THE FLYING time from New York to Moscow is 23 hours, and who wouldn't like to go?

The flying time to the farthest point on this planet is 60 hours, and constantly being shortened. The new freedom is upon us, and paired with it is the renewed necessity of understanding the atmosphere, the scene of our future revels. Weather was once a matter of life and death. The sailor, the hunter, and the herdsman had to read the skies aright or perish. Flood, drought, hurricane, and blizzard were not simply things that happened to somebody else's bank account. They were personal and deadly.

Then came cities and steam heat. Weather could be ignored by tens of millions. The subway populations forgot that it was still going on. The weather was handed over to the specialists. Of course, captains of ocean liners kept on consulting the barometer, and up in Vermont the sugarmakers never forgot that sap wouldn't run with the wind in the south. But for the tens of millions the weather was something you glanced at in the papers. An urban generation lost its feeling for weather and the old racial wisdom of the wind and the rain.

And now, abruptly, weather is once more a matter of life and death. The air is a tricky highway, and meteorology becomes as important a study as geography or arithmetic. It takes no H. G. Wells to forecast the schoolboy's coming homework. He will translate teletype sequences. He will know how to use gradient wind velocity tables. When he asks, "Dad, can I have the helicopter this afternoon?" it will be

understood that he knows better than to fly into the midst of a cumulonimbus. He will look down on this book as elementary because it is bare of beautiful equations.

The book is, I admit, innocent of calculus. Its aim is to present the fundamentals of weather, the primal simplicities that every flier must know before he can be sure of what is coming next. The atmosphere is the machine that must be mastered before a pilot dare enter his plane. It is a machine of such scope and intricacy as to seem utterly baffling to those who have not looked into its mechanism. Yet it answers its controls as sweetly and surely as a Liberator, which, in a way, it is. The weather, once understood, will never let you down.

Quite aside from the practical aspects of being air-wise, there is a curiously satisfying pleasure in having an intelligent interest in the weather. There have always been those who loved it for its own sake, as born anglers love fishing regardless of the catch. These weather-lovers are part scientist, part poet. They rejoice in the forms and colors that glorify the weather. They delight in extremes. They are gratefully aware that nobody can regulate the weather, nor charge admission to it, and are happy that it is forever beyond the reach of politicians.

Some of these weather-lovers become professionals, manning the weather stations, conducting experiments, and living in the benign stratosphere of higher mathematics. Most of them, however, remain amateurs. That is, they do not get paid for their predictions. They continue to make them, nevertheless, and love to explain why they were wrong. They and golfers understand each other well. To them also this book is fraternally addressed.

I would gladly make those honest acknowledgments for assistance which should accompany such a book if I were able to disentangle the long skein of indebtedness. I owe some-

thing not to be calculated to the good genius that bequeathed to me at birth an unquenchable delight in weather. I owe happy years of map-gazing to the Weather Bureau, which is also a never-drying fount of pamphlets. I owe much to the libraries browsed in and to the authors whose books I have pored over. The few titles in the bibliography appended represent only some of the latest and most helpful works.

I especially want to thank two friends, Mr. Fred A. Tower, a Weather Bureau veteran, and Mr. Richard Car-Skaden, whose keenness no weather can escape, for reading these pages in manuscript. Their interest and suggestions have been appreciated and of great value.

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CHAPTER 1

Forecasters' Tools

ANYONE who steps outdoors becomes, whether consciously or not, a weather forecaster. He glances at the sky and says to himself that it is going to rain, or it isn't going to rain. He will be right precisely in the degree that he has trained himself to observe and to remember.

Eyesight and memory are the primary instruments of this personal, habitual forecasting. Interest increases aptitude. Without it one cannot remember or even see. Interest focuses the eye and summons from memory a multitude of like skies observed over years for instantaneous comparison. These three faculties have been the fundamental tools of weather prediction since the Big Rain in Genesis. In fact, people interested in the weather had little else until Galileo invented the thermometer and Torricelli, his pupil, produced the barometer.

The barometer is an essential instrument for anybody who wishes to foresee the weather. It is as tricky as a circus clown—its antics will have their own chapter—but it does tell you the weight of the air column overhead, and this is valuable information, for weather is the result of change of pressure. The heavy, fairly expensive, mercurial barometer, which is meant to remain in one place, is the most accurate. The portable, and cheaper, aneroid tells the continued story well enough, and is constructed to furnish a graph. These barograph records are excellent instructors. Planes carry aneroid barometers called altimeters since the vital fact of altitude can be learned from comparison of pressures.

A thermometer is as handy for a weatherman as for a physician. The barometer takes the atmosphere's pulse; the thermometer not only tells but can be made to foretell its temperature, as will be shown. One can splurge in thermometers. They come devised to register maximum and minimum temperatures. The thermograph gives a continuous registration on a chart. Only a high-grade instrument of tested accuracy gives satisfaction, and the location and exposure are as important as the quality.

We live in a welter of temperatures. A man standing in a foot of snow may be breathing zero air, while at his knees the temperature may be 6° below, at his shins at the snow's surface 14° below, and at his toes where the air has been kept warm by the snow 14° above. A thermometer must hang exposed to ventilation yet be protected from the sun, rain, and radiation from ground or walls. The most satisfactory exposure yet found is within a double-roofed wooden box at eye-height from the ground, with slatted sides to give free passage to the air and ward off all other influences.

A wind vane, placed high and free of all artificial restraints, is the weatherman's right hand. He is always glancing at it, for the wind is a great tell-tale on the weather. The professionals must have their wind gauge, too, a cupped device called an anemometer. But the amateur will read velocities from nature less expensively.

The amateur, however, will want to know the amount of water vapor in the air. This is the far-famed humidity of human execration. It can be obtained from wet-bulb and dry-bulb thermometers. The wet-bulb is merely an ordinary thermometer with a bulb kept wet by a piece of muslin and a wick that lies in a vessel holding pure water. It must be ventilated by fan or swinging. If the air is not saturated, moisture will evaporate from the muslin and so cool the wet-bulb to a point lower than the adjacent dry-bulb thermome-

ter. The drier the air the greater the difference between the two readings, and the moisture content of the air can be found by consulting humidity tables. Professionals have elaborate psychrometers and hygrographs for the same purpose.

Anybody with a spot of ground can own a rain gauge, and should. If homemade, build it on the principle that the receiver have ten times the catching surface of the tube in which the rainfall is measured. This cylinder should be 8 inches in diameter and the rim stand 36 inches above the ground, horizontal. With the thin measuring stick graduated in inches and tenths, each tenth records one one-hundredth of an inch of rain. Less rainfall than that is called a trace. Wind currents affect the catch, and the gauge should be in as open a location as possible, away from trees and buildings.

Snowfall is more difficult than rain to measure accurately. The snow that collects in the rain gauge is to be melted for one's precipitation records, but to report its depth requires several measurements in undrifted places. New snow on old poses additional problems. Anything white, such as an old sheet, spread after the first fall will afford one means of gauging the next. New snow averages about nine parts air to one part ice crystals. Its water content varies greatly with the temperature. The custom is to estimate 10 inches of snow as the equivalent of an inch of rain.

Professional forecasters of the Weather Bureau, the major airlines, or independent concerns, add to their knowledge of weather conditions by tapping the upper air. They send aloft self-registering thermometers, barometers, hygrometers, and the like by means of kites, airplanes, and balloons. Better still, they sound the free atmosphere with equipments that radio back the temperature, pressure, and humidity of the air at different levels. They map the air and

are forearmed with information strata-deep that no garden weather-lover can attain for himself. Yet the amateur has the chance to see one end-product of all this research—the daily weather map. Except during a war, that is, and even then authorized persons can have weather information upon proper identification. This map is posted in the larger centers, is published (in reduced size) in newspapers, and can be had from one's nearest forecast district for about a cent a day.

The 19-by-24-inch map is the amateur forecaster's final instrument and joy. It is his daily love-letter from the skies. It blueprints the fundamental atmospheric situations the country over. It outlines the weather that is about to come his way. No matter how good an observer of the local weather a man may be, he can have no just estimate of the conditions twenty-four hours hence without some knowledge of where the air masses and their fronts are. It is no shame for him to lean on science in this way. After all, he wants to be right about tomorrow's weather. Also he can have the pleasure, once in a while, of beating the weatherman. The Government forecaster has to take in a lot of territory, while the local enthusiast has only his immediate neighborhood to care for. It is always fun to pit oneself against the great. But if your amateur is wise, he will keep his successes to himself. There are triumphs, but there are also certain tribulations in being one of the better weather prophets.

CHAPTER 2

Troposphere, the Weather Theater

SCIENCE never wrings its hands because it has reached the last frontier. There is always some direction in which to explore. With meteorologists it is up.

The atmosphere is an edifice of many stories roofed by space. Nobody knows yet how far up one would have to go to leave the last air molecule behind. Störmer reports that auroras may occur 720 miles above the earth.

If you could take an elevator up, the boy would call out the following floors:

First zone, troposphere, the weather zone. Its height varies from about 6 miles above the earth's surface at the poles to nearly 12 miles at the equator. Here is found the unstable air with both horizontal and vertical currents. Half of the total mass of the atmosphere is compressed into the first 3½ miles. Only the greatest storms reach higher than 5 miles. Cirrus clouds are thrown to the upper limits of the troposphere. The temperature in this zone decreases, on the average at the rate of 1° Fahrenheit for every 300 feet of altitude. This lapse rate, as it is called, varies because of the air's contact with lands and seas and their irregularities of heating.

Second zone, tropopause, the narrow layer of transition between troposphere and stratosphere. This ceiling of the weather zone lifts in summer, falls in winter. It lifts over the anticyclonic areas of high pressure and falls over the cyclonic areas of low pressure. In it the temperature is constant or even increases somewhat.

Third zone, stratosphere, the zone of even temperatures, (about –65° F. in its lower reaches), with winds parallel to the earth's surface. This level immediately above the tropopause is cloud-free, and with extremely stable air. Aviators consider this avenue of smooth, moistureless air the ideal medium for the future's long-distance flights. Its obstacles are being overcome. The deficiency of oxygen which would cause death at 20,000 feet can be eliminated by masks. The change in atmospheric pressure from 14.6 pounds per square inch at sea level to less than 2 pounds at 50,000 feet is countered by a steel-chambered ship in which pressure conditions may be maintained and the flier sealed from the cold.

At 15 miles up, our elevator would run into an ozone layer in the stratosphere. In the troposphere air, the ozone so heartily advertised by mountain resorts is represented by only the merest trace. But the extreme ultraviolet radiation of the sun noted at stratosphere levels, on passing through cold dry oxygen, changes it in part into ozone. In connection with this ozone-rich layer a rare iridescent cloud occurs.

At 24 miles we reach the first of two layers (the other lies just above the stratosphere, at 48 miles up) where meteors disappear most frequently. This is thought to indicate that a zone of greatly higher temperature exists, perhaps 200° F. higher, that is a rise from the –65° of the lower even-temperature levels to 120° or 130° F.

At 36 miles up, there is a layer that tends to absorb radio waves. Its cause is sun-action, as is proved by the fact that radio stations, especially the short-wave, have a greater range by night than by day.

Fourth zone, the ionosphere, begins at 48 miles aloft. In its lower portion occasionally are seen the noctilucent clouds, a faint glowing in the darkness of night, but of what composition nobody can be certain. In the levels above, from 55 to 70 miles up, lies the Kennelly-Heaviside layer, which reflects

radio waves back to earth and so keeps precious soap advertisements from being lost. Above it lies the region where the aurora borealis hangs its glowing draperies. The upper limits of the aurora vary steeply, but the intenser shows occur between 60 and 180 miles aloft. Their cause is considered to be electrons shot from the sun into our upper atmosphere.

Our elevator stops at their top limits. The remnants of our atmosphere go higher still. But the practical interests of the forecaster and the present-day airman lie well within the atmosphere, the behavior of which constitutes our weather.

Weather is air in trouble. In better days, before the recent ice age, historians of climate have found that the earth's weather was comparatively genial and uniform, a protracted succession of balmy summer days. There were immense periods of time when the atmosphere was not put upon by all sorts of distracting influences as it is now, and man—if he had been present—could have been born and lived his four score years and died without knowing anything but climatic quietude and peace. No droughts, no blizzards, no cold waves.

But man has never known anything but meteorological violence. The volcanoes and the ice-caps have seen to that. We live in a period of atmospheric turmoil. Three hundred and twenty-five volcanoes are now active. The polar ice-fields produce frigid and adventurous winds. The air is harried about by constantly changing pressures. The sum of these perturbations is the drama of contrasts we call weather.

Air itself seems the simplest thing there is—a smooth-feeling, odorless, tasteless, invisible gas. Rather is it a democracy of gases that consent to mix but decline to lose their identities. Air is mainly nitrogen (78%) and oxygen (21%), with the small residue divided among other gases—argon, carbon dioxide, hydrogen, helium, neon, krypton, and xenon.

The water vapor, dust, and salt particles present in the air are guests. They occupy space independent of the permanent gases which simply have to make room for them. The water content, measured by weight, may amount to as much as 5% in the tropics but is almost negligible in the Arctic. This moisture variable is the most important feature of all to the weatherman.

The atmosphere still might conduct itself in a staid manner if it were not held to a wrinkled globe by gravity, a globe tilted somewhat as regards the sun, and spinning from west to east at about 1000 miles an hour. It is subjected to an ever-varying reception of heat, to a constant whirling, to never-ending expansions and compressions. It is small wonder that the air is fretful, unstable, and perpetually rushing around in search of its lost equilibrium.

No invisible cloak of fairy tale was ever more marvelously made than our earth's garment of air. It never wears out. It is elastic enough to stand the strain of all its stretchings and compressions. It is fluid enough to permeate our most delicate tissues and so prevent our collapse under the 14 tons of atmospheric weight we carry around. A snowflake can parachute through it without the disarrangement of a crystal. Yet it can transport a billion tons of water inland from the sea without spilling a drop. Its power is inconceivable, yet its gentleness—with a few exceptions—has permitted us to endure on a slippery ball for uncounted ages. It is the very mother of grace, as anyone who has watched ripples or the flight of leaves knows well. But it is the very devil to know and understand.

CHAPTER 3

The Permanent Air Pattern

Like society, weather is a global unit, interknit. A change of atmospheric pressure over Siberia has later repercussions in New England just as surely as our injustices to the Chinese people recoil upon our own heads. The impulsive flutter of a bird's wings, when the air over Colorado is in a certain state, may start a wave motion that drives ships ashore in Ireland. It adds interest and dignity to one's spoonful of local weather to consider the vast kitchen it was brewed in.

Probably every adult remembers the diagram in his school geography that showed the general circulation of the earth's atmosphere. This over-all pattern is still valid, for the air at the equator continues to be warmer than the air at the poles, and the earth still turns from west to east. Cold air is compressed air, denser than warm air, and therefore heavier and an easier prey for gravity. Cold air therefore descends, meets the earth's surface and spreads, pushing out of its way any warmer air it runs into. The easiest escape for the warm air is up. We say warm air rises, and so it does, but the thing to remember is that gravity has a lien on it too, and the air has to be pushed up before it will go. Even the hot air over a concrete tennis court is not *drawn* up. There is nothing to draw it, but there is gravity to pull the denser air down.

If the atmosphere were unsettled only by heat and cold and their resultant air densities and differing pressures, the pattern of the earth's winds would be a north-south flow, and nothing to worry about except their gait. But the air moves

over the surface of a merry-go-round and the motion goes to its head. It never can advance in a perfectly straight line, although the curvature is sometimes slight. Further, it is retarded by friction. Its broad highway shifts with the seasons. The gathering-in of space at the poles adds complications. And it is always running into mountain ranges, flattening over oceans, hounded by the calendar with its disturbing inequalities of solar radiation receivable. Yet in spite of all this, a general system of air transport is effected. The grand roller-coaster runs on its endless track, and the man who could seat himself on a parcel of air and go with it would have a glorious ride.

The doldrums is a good place to start. They form a belt of nearly uniform low pressure at the equator. Winds from northeast and southeast converge and neutralize each other. It is a region of light and variable airs—the steam plant of the troposphere. Its air under this heating is constantly rising as is evidenced by great cumulus clouds. The only direction for it to flow next is poleward. As it goes north (and this book is selfishly concerned only with the northern hemisphere) in response to the pressure gradient, it always veers somewhat to the northeast and then to the east in response to the eastward rotating earth.

As it proceeds, the distance of this parcel of air from the axis of the earth is growing less, and its velocity must increase. That is, since it is covering more degrees of longitude in the same unit of time, it has to move faster to make room for the succeeding air. In the stately verbiage of physics this is called the law of conservation of angular momentum. When the air is returning from the pole, the velocity is correspondingly decreased. As a matter of observation, the wind's velocity at latitude 30° where this acceleration transpires is not as much as it should be. So the air piles up somewhat and forms a high-pressure belt, the subtropical anti-

cyclones of the oceans, and some of the accumulated air subsides, sinks back to earth, in these regions. The rest continues aloft as a westerly wind, but headed poleward at an angle.

This latitude 30°N. was given the name of *horse latitudes* by sailors, although nobody knows why. Presumably some calm day (and an anticyclonic area tends to calm) induced some jovial tar to suggest to the first mate that they should get a horse. Far stranger is the fact that staid scientists should keep the name. The air that here leaves the main current to return to the equator blows from the northeast and in steady tread, and these winds are known as the northeast trades. It was only by coincidence that Columbus and his successors used them for commercial purposes. The name has nothing to do with trading.

At about 60°N. the southwest westerlies meet a cold northeast stream of air from the polar ice-cap. Being warmer, it rises over this polar layer and pours on into the polar regions where it is chilled. The polar flow at the line of convergence cannot rise up and take part in the poleward-going stream. It is not warm enough to rise. Therefore it tends to back up and accumulate in its Arctic habitat. This front, at the convergence, is called the polar front. When the cold air piles up excessively it breaks through in places southward, and is the cause of cold waves, cyclones, and the other large-scale disturbances of middle-latitude weather. But while it is doing this it is returning air to the general sweep and pattern of things. The United States happens to lie in this zone of strife, with the ascendancy continually shifting from one main stream of air to the other.

The high-pressure belt at latitude 30° and the low-pressure belt at latitude 60° do not form uninterrupted girdles around the globe. Oceanic high-pressure areas are more stable than over continents with their great temperature

variations between summer and winter. They form more or less permanent cells. Near the horse latitudes there are four of these cells about 90° in longitudinal width. Each cell thrives under an anticyclonic circulation, that is, outward in curves clockwise in direction. Each cell tilts upward from east to west, bringing the upper levels of the anticyclone farther west than at the ocean surface. At about 60°N. similar cells of like size but with cyclonic, that is, inward and counter-clockwise, circulation, tilt from the west upward to the east.

The moving fronts, cyclones, and anticyclones, can be visualized as cogs in the vast streamlined machine of the atmosphere, taking up or letting out the irregularities, or accumulations, in an otherwise orderly transport of the hemispheric air. It happens that most Americans live in this machine-room where you can all but hear the gears shift and the cogs grind. It is these interactions of the great cyclonic and intercyclonic wheels that keep the Weather Bureau's nerves on edge. For the wheels change in diameter, in location, in speed of revolution, and in the track they take.

Until very recently forecasting was done on a two-dimensional basis. The pattern of a morning's weather was penciled down on a flat chart and read from left to right. It was very like having a view of a passing pedestrian's feet and being obliged to guess his nature and destination from that glimpse.

Today the forecaster is better off. He has more data to go on, because of reports from the upper air and because mathematics has come to his aid. New concepts of air circulation and new treatments of data have made possible a new accuracy in prediction. To understand what weathermen are talking about today, one must know something of air masses, the wave theory of cyclones, and frontal methods of forecasting. Meteorology is knee-deep in calculus. In the Weather

Bureau offices it rains thermodynamics. It is always high pressure in those offices after 7.30 A.M. The science has come a long way in twenty-five years. The fundamental air circulation is the same as it always has been, a comparatively simple pattern with fancy borders. But in the light of the new knowledge it has become vastly more exciting.

CHAPTER 4

Nature and Habits of an Air Parcel

UNTIL we took to flying a few years ago, wind was purely a horizontal proposition. It is true that we saw newspapers whirled above our heads in gusts and read of babies being deposited in treetops by tornadoes. Climbers knew that breezes blew up the windward sides of mountains. The more observant had watched thunderheads mushroom upward into white domes of cloud. Balloonists had reported terrifying updrafts in such thunderheads. And weathermen knew of convection in all its forms, from the great tropical upflow of the planetary circulation to the midge-like dust-whirl lasting a few seconds. But few people suspected that the up and down movements of the air were as constant and as important as the horizontal. In fact, a poll would probably have established the fact by vote that they did not exist.

It would have seemed similarly ridiculous to use the expression "a parcel of air." As well say "a piece of eyesight," or "a bundle of sound." Air, as any sensible man in 1910 might have objected, is a continuous medium. Air is simply space that happens to be occupied by gas particles. It is one and indivisible.

And so it is. But the flier has found it full of bumps and billows and eddies and cascades and even geysers that could shoot him aloft hundreds of feet in a minute. And when the weathermen looked at it closely, they found the air near the earth's surface as spotty as a leopard's skin. There were patches of heated air rising from plowed fields and sandy

plains, while over water and wood-lots the air was at the same time sinking. The continuous medium was taking on the attributes of parcels. A cloud was a remarkably parcel-like affair. All over the earth myriads of little air bubbles were rising and falling, and occasionally stagnating in a big air mass. Convection became, in the understanding of weather, as important as gravity. Convection is the technical word for the upward or downward movement of a limited portion of the atmosphere. Convection is the cause of practically all of the precipitation on earth. It is also the cause of most of the flier's trials. We can study it most easily by considering a parcel of air under certain circumstances.

In nature, as in life, there is a price for everything, and it is paid in energy. A parcel of air lying above a plowed field is heated by the ground somewhat faster than by the grassy fields around it. It expands and becomes lighter than the surrounding air. The denser air sinks, forcing the lighter up. As the lighter air expands in volume it must make room for itself by pushing other air away, and this pushing requires energy, the only source of which is in the heated parcel. This parcel therefore cools as it rises. The usual rate of cooling is 5.5° F. per 1000 feet of altitude for dry air, and this rate is called by science the adiabatic rate of cooling. Adiabatic is a term so often used that its meaning should be mastered. Adiabatic changes of temperature are those that occur only in consequence of expansion or compression accompanying a decrease or increase of atmospheric pressure. The parcel's temperature was neither added to nor taken away from by any other process.

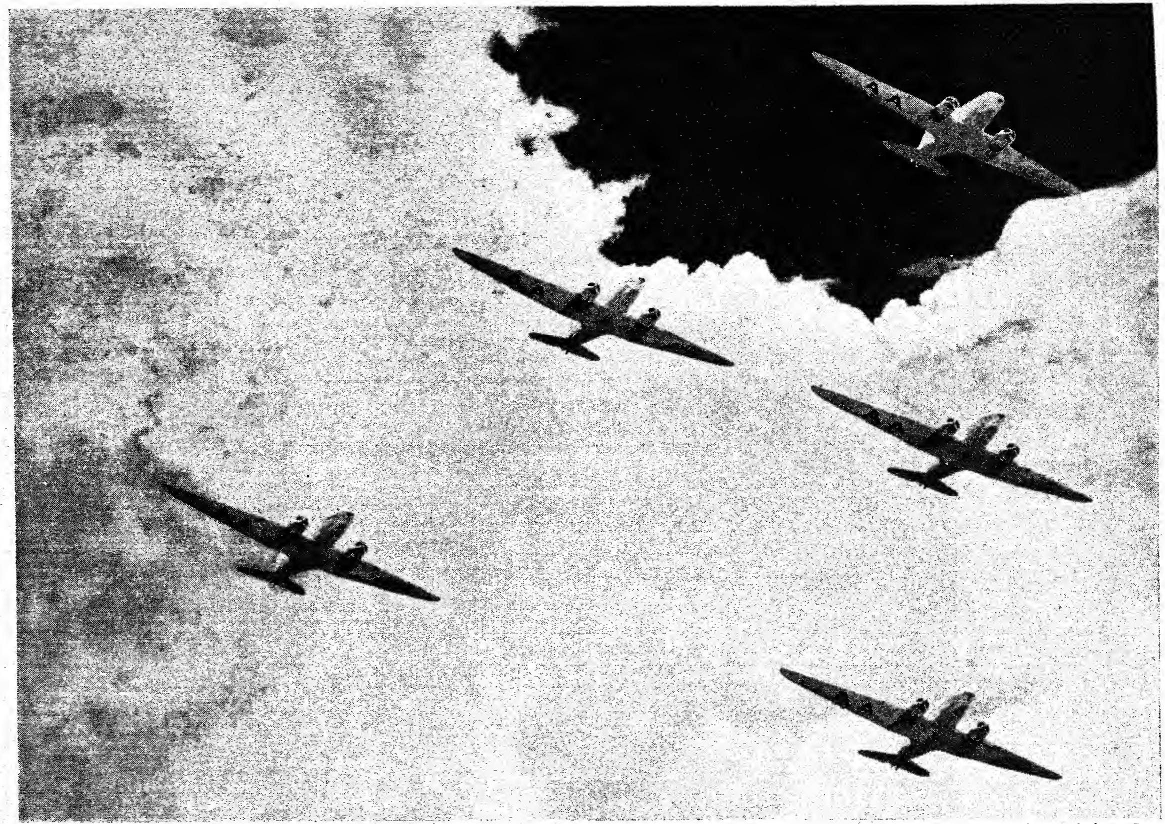
Now as one climbs into the air, on a mountain trail or by plane, the temperature falls gradually and irregularly. This fall is at the average rate of about 3.5° F. per 1000 feet of altitude, and is called the lapse rate. An irregular lapse rate is the rule, but it is steady in layers between zones of irregu-

larity. This lapse rate of cooling is slower than the adiabatic rate for dry air. The rising parcel soon finds itself cooler (and denser) than the surrounding air through which it has been lifting, and its tendency is to halt and return to its original level. No particular disturbance has been created and the air is stable.

So much for a rising parcel of dry air. Saturated air is another matter. Saturated air does not cool so quickly when rising, and the reason is that saturated air soon reaches its dewpoint, condensation begins, and condensation yields not only water but heat. This heat added to the parcel by condensation restrains the cooling, and the moist-adiabatic rate is less than half the dry-adiabatic. It is not constant enough to be given so precisely as the lapse rate, but roughly it amounts to about 3° F. per 1000 feet of altitude.

A descending parcel of saturated air has other habits. It starts to heat at once, since it is compressed by increasing atmospheric pressure, and this heating process causes the parcel to become unsaturated and it assumes the adiabatic rate of dry air, that is 5.5° F. per 1000 feet of fall. It holds no more water 1000 feet lower but it *can* hold more. In mountainous regions this idiosyncrasy has vivid practical effects.

A moist parcel of air from the Pacific, say, approaches the Canadian Rockies with a temperature of 35° F. It is forced over the Rockies at the 10,000-foot level and is cooled to zero. Most of the water is squeezed out and the dried air descends, warming up at the adiabatic rate of 5.5° F. per 1000 feet. If it descends 8000 feet, it will have a temperature of 44° F., a gain of 11°. East of the Rockies in Alberta the extremes noted are far greater. A descending body of air can raise the ground temperature 40 or 50° in a matter of minutes. This chinook is the great snow-eater. My favorite western cartoon pictures a man in a sleigh racing a chinook, with the snow



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feet deep in front of the horses and bare ground just behind the sleigh. The reality can be almost as startling.

With these habits of dry and moist air parcels in mind, the forecaster is armed to detect the all-important stability or instability of the air over any area for which he has observations. The professionals draw pressure-temperature charts from data given by air soundings as to pressure, temperature, and humidity. To the neophyte one of these charts (with its vertical temperature lines, horizontal pressure lines, slanting lines for dry and moist adiabatic changes, broken lines for saturation curves) resembles a heavy rain of meteors. A trained meteorologist pulls many a rabbit from this complicated hat. He can evaluate the physical changes of air parcels, layers, and masses, as they move up and down through the atmosphere. Weather is largely determined by this transfer of heat and moisture. The rest of it is determined by the forces that create and maintain atmospheric motion. Since energy is required to create this motion, it is important to arrive at the amounts of energy available.

The adiabatic chart tells all these things. It signifies whether conditions suppress or favor vertical motion. When it announces that convection is present, the weather-seeker knows that he can anticipate clouds of the cumulus family. The chart provides a key to condensation levels and he can then look for showers, thunderstorms, squalls, hail, rough flying.

When the lapse rate is smaller than the dry-adiabatic rate, he can be certain that the air column is stable. When the lapse rate is larger than the dry-adiabatic, the air column is unstable, and these situations hold regardless of the relative humidity so long as the air is not saturated. The same conclusions are reached for saturated air, but when a stable mass of saturated air is lifted, condensation is likely to occur.

Since this book is for those of us without access to the

upper atmosphere, no charts are given. We are not devoid of clues, however. Clouds radio signals as to the stability of air parcels almost as effectively as balloon-borne meteorographs. Clouds of the cumulus variety are merely the Grecian scrolls topping the invisible columns of rising air. For the moment we postpone clouds and pursue the youthful air parcel in the aggregate called an air mass.

CHAPTER 5

The Air Mass as Parent

An air mass is a widespread body of air which is uniform, horizontally at least, as regards its temperature and humidity. It may be almost continent-wide and as deep as the troposphere, although it rarely is. Its uniformity is approximate, of course, since a huge incubus of air a thousand miles wide cannot be completely homogeneous.

It is fortunate for meteorological sanity that there are these great masses of mobilized air which are anchored for long periods over one area. They simplify the map. Their grave semipermanence adds a quieting dignity to the general scene. They are dependable. They afford bases for prediction.

An air mass is caused by air settling, or at least lingering, over large regions that have uniform surface conditions of temperature and moisture and sunshine. An air mass is a sort of Australia lost in the vaster Pacific of global ocean. Since air is influenced by the land over which it tarries, the longer it stays, the higher into it these influences are likely to reach, and the more homogeneous it grows. The outcome is a vast brood pile of air which has taken on a unity, even a personality, from its source until it can be given a name, charted, and followed through its life-history. For these huge blocs of air migrate, since on this rotating sphere nothing is allowed to drowse in dreamy indolence forever.

Air masses fascinate meteorologists, partly because they are a fairly recent discovery, but chiefly because they are a

major fount of weather. They bear the same relation to our climate as the greater national parks to our terrain. They are weather sanctuaries, the breeding-place of large-scale air currents that are divergent. Only the great anticyclonic wind systems afford the stability needed to accumulate the vast bodies of air of sufficient alikeness that comprise an air mass. And there are only two habitats favoring this accumulation —the centers of the continents and the high-pressure regions of the oceans. These have been given four names: polar-continental (Pc), polar-maritime (Pm), tropical-maritime (Tm), and tropical-continental (Tc). Asia, Siberia, China, Canada, and Alaska nurse the polar-continental air masses into being. The northern Pacific and Atlantic breed the polar-maritime. The tropical Pacific and Atlantic and the Gulf of Mexico are the tropical-maritime source regions for air masses that concern the United States.

Scientists love to classify, and since Bergeron introduced the idea of air masses into meteorological literature and forecasting, the air mass has been pretty well taken apart and pigeon-holed. The Byers chart of regions of surface air masses of North America runs to thirteen sources. His list of predominating types of influences that modify these masses comes to fourteen items. Of the fifteen chapters of his *Synoptic and Aeronautical Meteorology*, four are devoted to the air mass, that is, 71 pages out of 271. The air mass, as comparative newcomer to meteorology, should feel complimented.

These refinements are for professionals. The amateur forecaster needs only to know that there are two main kinds of masses (cold air and warm air), where they come from, and what they do.

Stated most simply, a cold air mass is a mass of cold air that is usually (though not always) colder than its underlying surface. Its source is in the colder north, the subpolar

regions, but in winter it builds up over our continent as far south as 30°N. It is characterized by stable stratification, low temperature, and low specific humidity. Visibility is good within its bloc, except when it has traveled and picked up, dust, heat, or moisture. The clouds of a continental cold mass have high bases, rarely lower than 2000 feet. If there is precipitation, it takes the form of snow-flurries or showers. A maritime cold mass has greater vapor content and the greater instability that increased humidity causes. When a continental cold mass passes onto the ocean in summer it becomes even more stable, but in winter its instability increases. But the shower activity counteracts the turbulence caused by heating from below, and equilibrium returns. The properties of a continental cold air mass can be recognized by reviewing the nature of a January day when the wind is in the northwest, the sky is cloudless, the air cold, the barometer high. It will bring the same sort of weather in July, but with higher temperatures, more clouds, usually of the cumulus variety, and more variable visibility. Cold air masses, however, are customarily marked by fair weather and stability.

The warm air mass must not only be a mass of warm air but of air that is warmer than its underlying surface. The chief sources of warm air masses are the subtropical oceanic anticyclones. These maritime warm air masses may have high moisture content but remain stable, for the air is cooled from below when it moves to a colder region, and this hinders turbulence. The visibility is often poor, due to the high relative humidity. The clouds are of the stratus variety, owing to air layers of temperature lapse-rate inversion. When a warm air mass invades a warm continent in summer the instability increases rapidly; but in winter the stability is increased, and fog may be widespread.

Since abstractions are dull, the vagaries of wandering air masses will be gone into more concretely later. It is enough

now to say that the great semi-permanent air masses are reservoirs of nearly uniform air from which important weather influences flow. When they start to migrate, they become more complex. Like nations at war, they advance along fronts, and that is where most weather troubles start.

CHAPTER 6

At the Front

AIR-MASS frontiers are often strangely abrupt. Since it is the tendency of cold air masses to move south and warm air masses to move north, somewhere along the fronts there is perpetual collision, strife, and invasion of each other. The comparison with war is irresistible, and the word *front* is used by weathermen to signify this line of conflict.

It is also called *a surface of discontinuity* because the previous long-maintained continuity of temperature, moisture content, wind, and pressure in the parent air mass is disrupted by the sudden meeting with the different characteristics of the hostile air mass. This zone of contact is so narrow in comparison with the breadth of the air masses involved that it is marked on the map by a line.

An invading air mass does not march wholly upright like an advancing wall. As a cold air mass proceeds, the denser air is being pulled down to earth by gravity, and when it meets the ground it tends to flatten out ahead. Consequently when this earth-creeping air meets a warm air mass, whose air is lighter, it underruns the southerner. The cold invasion, therefore, takes the form of a wedge. The slope of this wedge is roughly 50 to 100 feet in the mile.

There are four main fronts that influence our weather: the Pacific Polar front far out to sea; the Pacific Arctic front with one flank south of Siberia and the left stretching down the Canadian Pacific coast and into the United States; the Atlantic Arctic front running from Iceland into the northeast; and the Atlantic Polar front curving from the

south central states up to Nova Scotia and beyond. These are the frontal zones in winter. In summer the Arctic front, from Iceland, remains almost in the same position but is weaker. The Pacific Polar front has taken the place of the Pacific Arctic front but extends only along southern Siberia and across Alaska. The Polar front crosses our continent from Newfoundland and along southern Canada.

The United States is our hemisphere's chief battleground. In winter the polar air masses build up over the frozen continent into great blocs of clear and frigid air. At the same time the tropic masses, moist and warm, raise their convections miles into the atmosphere. The clash is violent and is always happening somewhere along the lines.

The old-style weather map was a comparatively mild-looking affair of ellipses and curving isobars, with "highs" and "lows" to mark the extremes of pressures. The highs and lows still cross the map, but now the discontinuities of surface are revealed by sharp changes in direction of the isobars. This is known as a "kink." The reason for the kinkiness is the rapid change in temperature, pressure, and wind at the time the front passes over the observer.

This time is usually brief, often a matter of minutes. A well-developed front may have a transition layer (the zone of mixing) only a few hundred feet thick in the free air. Along the ground the width of the frontal zone will be wider, but not so wide that the drop of temperature, the lift in pressure, and the swing of wind direction are not very marked. Everybody has noticed the darkening cloud and sudden cooling before a wind-shift.

The barograph enters this moment on the chart as a V. The graph may have been falling for days. Then the fall accelerates. As the minute of discontinuity arrives with the cold air, the pressure is put on, the barometer responds with a sharp rise, and the graph shows the kink.

Wind follows isobars with always a slight inward drift toward the lowest point of a pressure center. When the kink comes in the pressure curve there is also a kink in the graph of wind direction, known as the wind-shift. A front is a wind-shift line. The wind can swing from south to northwest in one stride.

Meteorologists recognize four sorts of fronts: warm, cold, stationary, and occluded, which means closed up.

A warm front advancing from the southwest normally invades colder air. Being lighter, it slides up over the retreating cold wedge. As it is warm and moist, when its temperature falls enough the condensation projects a cloud cover over a large area, sometimes to a height of 20,000 feet.

This slope is far more moderate than for a cold front, being 1:500 rather than 1:100. There is a regular cloud progression, from cirrus to cirrostratus, to altostratus, to nimbostratus. When the warm air is comparatively stable, the rain or snow falls evenly, usually in increasing intensity, but without sudden changes. In summer, when the air is warmer and less stable, a showery type of precipitation follows.

The advancing cold front, which is steeper and faster, does not throw out a cloud system comparable to the warm front's. There is, however, considerable turbulence with squalls along the line of most abrupt discontinuity.

A front is stationary when the cold air moves parallel to the frontal surface along (or sometimes above) the earth's surface. In such case the warm air may travel either parallel to the frontal surface or at some slight angle to it. A stationary front does not remain so for long. Either the high pressure behind the cold front increases and the cold wedge begins to move forward again, whereupon it becomes a cold front, or the pressure decreases and the front weakens to the point of dissipation.

Since the massive air of a cold front is heavier and usually

moving faster than the disturbed air of the warm front, it is likely to catch up to the warm front and close in on it the way a door closes. It shuts on the hinge of low pressure where the warm and cold fronts first touch. The warm air is squeezed and escapes up. This is part of the routine of a cyclone. With nature one must be patient; at last, however, we are ready for a storm.

CHAPTER 7

The Cyclone Wave and What Happens

PRIOR to 1918 when J. Bjerknes finished dissecting the cyclone, a disturbance of this sort was accepted as an area of low pressure rather mysteriously initiated by an upflow of warm moist air and kept going by the heat released through condensation. Thermal convection was supposed to be the key that unlocked the works.

Closer scrutiny, however, revealed three major facts of the cyclone that thermal convection did not explain. It failed to show why cyclones, and bigger ones at that, should occur in winter rather than in summer when thermal convection was in its glory. It did not account for the occasional cyclone that gave no precipitation even when well developed. And it left out of the story the strange fact that the upper troposphere is often actually colder above cyclones than over the cold air anticyclones accompanying them. The thermal convection theory was considerably damaged by these findings.

Further study revealed an impasse in the air circuit. The north-south transfer of air, because of temperature-caused pressure contrasts and the eastward deflection due to the earth's spin, induces a fullness in the middle latitudes that had not been taken into account. There is an eastward increase of pressure which must continue across the whole width of the north-moving sheet of air and around the earth. But if this happened, the pressure would be greater at the end of the circuit than at its beginning, that is, at the same place, which is impossible, even to the weather.

Therefore a correction must take place, here and there and now and then. The difference in pressure which does occur must be cared for. So a pleat is taken in the atmospheric skirt at the juxtaposition. It is a pleat, a wrinkle, that moves, however, as a sort of wave, and a cyclone has begun to be.

At first there are two air currents flowing side by side, a warm tropical current and a cold polar current flowing in opposite directions. It is the tendency of cold air to force itself under the warm air. Starting with a wedge, the polar current noses little by little beneath the tropical stream, and as the surfaces collide billows form, just as wind makes waves on a river.

As these billows increase in amplitude, the frontal surfaces become more unstable. Just as one sees the instability of waves on water growing with the increase of the wind, so on the frontal surfaces of the two winds the swell becomes longer.

The first indication of an incipient cyclone is a slight indentation of the equilibrium front on the weather map. If this wave is shorter than 400 miles, it will probably remain too stable to develop into a cyclonic formation; and if it is longer than 2000 miles it will be too cumbrous to achieve cyclonic structure. If between 400 and 2000 miles this indentation will accentuate and become wave-like under increasing wind stress, and a cyclone is launched.

This unstable part of the front, now out of balance, continually deepens. The air, always seeking to adjust itself to some equilibrium, is drawn in toward this weak point. Thanks to a combination of earth-rotation and frictional conditions, the area develops the large whirling circulation of a cyclone with winds inward-flowing and counter-clockwise. The warm air from the south advances to the right, the cold air pushes down from the left, and the whole system,

1500 miles across in its maturity, slides from southwest to northeast in accordance with the prevailing wind directions aloft.

We live in a whirl. The cyclone cycle can be seen in its orderly sequence at least once a week. The program is, in a normal cyclone, as follows: (1) the clear sky of a departing anticyclone gives way to a cirrus-streaked sky as the first evidence of an approaching warm front. The wind veers to an easterly direction. (2) The cirrus thickens into cirro-stratus as the warm front air grows thicker. (3) The center nears, with altostratus and nimbostratus from which rain or snow falls. Pressure, which has been falling, now decreases rapidly. Temperature, which has been rising slowly and steadily, now increases rapidly as the surface front passes the observer. (4) The cold front arrives with swift wind-shift from south to northwest, a rise in pressure, a fall in temperature, with turbulent squall-line clouds and then a hastened clearing in a fraction of the time it took for the clouding up in advance of the warm sector.

Compared with the height of the atmosphere a cyclone is a mere disc, like a victrola disc, with the hole in the center as the low-pressure point. The best analogy is the tidal wave. Nature likes to use the same form over again in different ways. Visualize a calm sea. As the tidal wave approaches, a long swelling of the water will take place and grow into a vast wave formation which becomes a curling crest. The crest, previous to breaking, spirals over, rolls forward in a turmoil but still keeps its general curling motion until dissipated. And so with a cyclone. First seen, say, as a wave over Texas, it becomes a whirling entity over Missouri. At its hours of greatest intensity the warm air draws the cold air from the northwest into this whirl from the south, the temperature contrasts providing the causes of condensation and energy. Over New England the cold front will have largely

overtaken the warm sector and the intensity begins to wane. By the time the cyclone has reached Newfoundland, it is occluded and done for. The warm sector has been squeezed to upper levels, and cooled adiabatically as it was lifted.

Three features can be noted. The direction of the wave's components is such as to keep the colder air always on the left of the direction in which the wave is moving (in the north hemisphere). The greater the wave length, the more rapid the components of its motion. And the greater the difference of densities between the two air masses which formed the discontinuity, the greater the rate of propagation of the wave. This shows why winter cyclones are bigger, faster, and more intense than the summer variety.

The development from the first sign of a wave disturbance to true cyclone ordinarily takes from 12 to 24 hours. The cyclone then takes another 12 to 24 hours to reach its maximum intensity and strongest winds. By the fourth day it is living on the kinetic (wind) energy already created, and friction gradually dissipates this until the circulation ceases, and the air is caught up by surrounding currents.

The disturbance set up by a cyclone affects the atmosphere vertically for miles. The tropopause sags in a wave trough, which grows deeper as the cyclone occludes and is left behind by the storm below.

Since cyclones are created by the discontinuities of opposing fronts, and since these fronts are as persistent as the rotation of the earth, it follows that storms are always somewhere in the process of being born. It is a rare weather chart that contains no "low" even for the United States, and sometimes there are four or five on the map.

The extratropical cyclone—as distinguished from the tropical cyclone, the hurricane of the West Indies—is the largest of this earth's storms although not the fiercest. Its average diameter of about 1500 miles is impressive enough,

but on the ocean a cyclone has room really to spread out. It reaches its vastest in the Aleutian low which is a roundhouse for cyclones. Just as there are regions where the atmosphere heaps up in permanent highs, so there are areas where low pressure persists. These areas give birth to an endless succession of storms, and they attract traveling lows to them and renew their energy. The Icelandic low, caused by the meeting of the warm waters near the coasts of Greenland and Iceland with the continuous downflow of icy air from these lands' snows and glacier caps, is a companion haunt of cyclones. North American weather is fundamentally affected by the size and intensity of these two great cyclone nurseries.

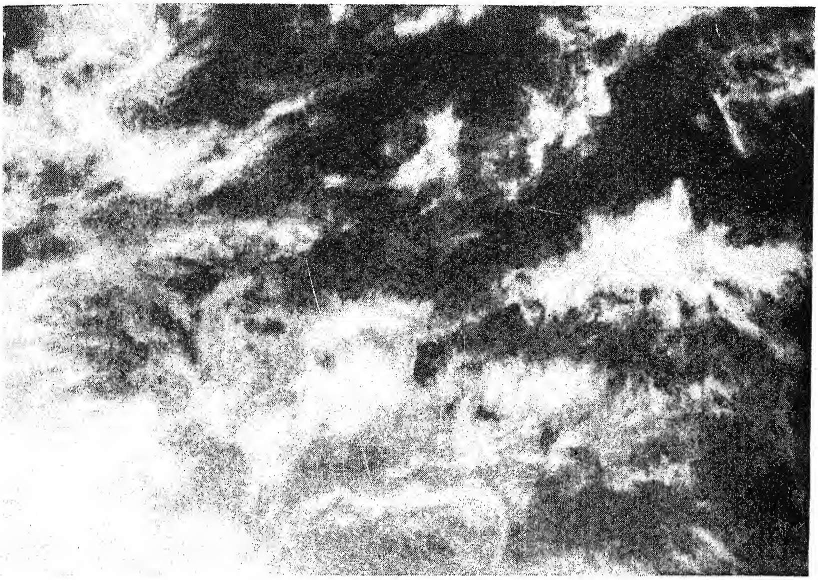
In the fascinating fictional life-history of a cyclone, *Storm,* Mr. George Stewart's heroine, Maria, is conceived in the expanses of the western Pacific, spends her youth traveling eastward, meets a spouse in the shape of a cold high-pressure system over western North America, and devotes much of a vigorous adulthood to destruction over California. This unique novel proves how exciting sound meteorology can be when realistically portrayed, and is probably the first weather book ever to make the movies.

Cyclones, always moving in a general west-to-east course, breed in great numbers in the Philippines, within or off the coast of China, or the Siberian frontal zone. Their favorite track passes the Japanese Islands, crosses the Bering Sea, and then moves southeast across the Gulf of Alaska, to move into our continent most generally in the vicinity of Vancouver Island. They then take a fairly direct easterly course, with a slight deflection southward over the Great Lakes, and pass out the St. Lawrence to Newfoundland. Other storms from the North Pacific fare farther south, entering over Washington, Oregon, or California, but they practically always recurve to the northeast before reaching the Missis-

sippi and take the main St. Lawrence-Newfoundland thoroughfare toward the Icelandic Low.

Sometimes cyclones originate in our Southwest, or in the Gulf of Mexico, and travel nearly northward to the Great Lakes before swinging into Cyclone Route No. 1, via the St. Lawrence. Often a storm will originate on or just off the Atlantic coast, grow rapidly as it parallels the coast north and northeast, and crossing New England and Nova Scotia head for the same old rendezvous. As the fronts on which these cyclones are being born as waves are advancing and retreating with the ever-moving seasons, the tracks of the cyclones change too. Observers soon learn what to expect when the Weather Bureau makes its first announcement of a new cyclone appearing in the North Pacific, Central Pacific, Northern Rocky Mountains, Colorado, Texas, East Gulf, South Atlantic, or Central Atlantic. Each point of origin tends to appoint a special track, which of course is always being modified by all the pressure points of interest along that track.

Any man who enjoys playing railroad is likely to delight in these supernal freights and expresses on our atmospheric routes. There are races, shiftings, collisions, even back-trackings, and halts on sidings. There are magnificent streamlined cyclones with centers traveling with the speed of our extra-fare trains. And there are locals, especially in summer, hot and dusty as any up-state mixed freight. The tables of averages (15.6 miles per hour for a winter cyclone in the United States, and 10.9 in summer) have had to take in everything, all the weak lows. But it is not unusual for a Texas cyclone to move to the Ohio valley between maps, that is in 12 hours, and a storm over Louisiana may reach Hatteras in that time. The winds, clouds, and precipitation in these storms will be discussed later. This chapter is occluded by the pursuant cold front and its anticyclone, which we must now take up.



U. S. Dept. of Agriculture, Weather Bureau

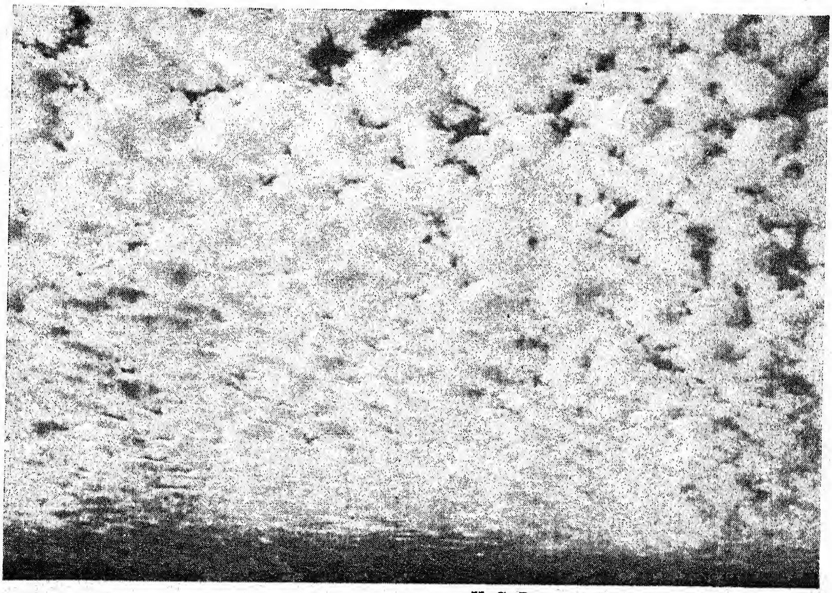
CIRRUS FILOSUS

U. S. Dept. of Agriculture, Weather Bureau

CIRROSTRATUS

U. S. Dept. of Agriculture, Weather Bureau

CIRROCUMULUS



U. S. Dept. of Agriculture, Weather Bureau

ALTOCUMULUS

CHAPTER 8

Anticyclone, the Weather's Rich Uncle

WHATEVER goes up on this planet must be lost to space if it doesn't come down. Since even a small loss extending over millions of years would bankrupt so small a store of air as we have, it is clear that the air thrown aloft by the cyclone centers must return. And so it does—drier, colder, denser—and known as an area of high pressure, an anticyclone. It brings the kind of weather that is hailed most fervently by the human race (unless too cold), for people were made to be joyous, and this slowly subsiding air with its attendant sunlight is atmosphere at its most tonic and delightful stage. It is the weather's rich uncle that chases off the cloudy cyclonic villain.

As usual, however, it is the villain that gets the most attention, even in meteorologies. In Petterssen's chapter, "Cyclones and Anticyclones," the cyclone is given ten pages, the anticyclone nineteen lines. Humphreys does a little better by the anticyclone, giving it five pages as against nineteen to the cyclone. Yet the anticyclone is intensely interesting, it provides somewhat more than half of our continental weather, and it is money to the airlines.

There are two main sorts of anticyclones—those that stay at home and those that travel. The anticyclones of fixed abode fall into two classes. One, the radiational, belongs to the extensive ice-cap over Greenland where pressure is always high because of the excessively continuous low temperature, due to great elevation and the radiation from the snow under

clear skies. (There is another such permanent anticyclone over Antarctica which is even greater.) A similar though smaller radiational anticyclone builds up over Canada's snowfields in winter, loosing cold waves over the Plains and northers upon Texas.

The second main variety of anticyclone is occasioned by mechanical means. The atmosphere between the trades and the westerlies is subjected to a squeeze. The resultant ridge, or barrier, is however also subjected to the push of interzonal circulation which is even more peremptory and so breaks through. This barrier-bursting leaves islands of high pressure which seasonal changes do not much affect. They do oscillate and occasionally a move closer to our shores than usual brings droughts. The southeastern United States at times parches under the clear high-pressure skies of the Atlantic anticyclone.

The common anticyclone of our weekly weather is a migratory complement to the cyclone. They are partners in a gigantic waltz. The lady, it is true, whirls counter-clockwise, while the staider anticyclone blows around in a clockwise direction. In this dance the anticyclone catches up with the cyclone and squeezes her to death. But sometimes she leaves him behind and the weatherman prints "high" over the Mississippi Valley while "low" is whirling out to sea from New England. It is this rather simplified separation on the charts that suggests a divorce between this couple whom nature has originally joined.

Anticyclone winds are sometimes severe at the cold front, strong for a few hours afterward, and then diminish until they become light and variable. These winds, from one of the westerly directions, have an outward push and are supplied by descending air at higher levels. This air is thus adiabatically warmed and laps up the high and medium clouds. The greatest depth of cold air is, surprisingly, well in advance of

the maximum pressure. The active polar air, heaped in a wave, leaves the heaviest, less active, air to subside. It is in the area of subsidence that we enjoy the still, bright, jeweled days of winter, or the unhumid summer days of exhilarating clarity.

The magnitude, frequency, and speed of advance of anticyclones corresponds with their preceding cyclones but their life-lines differ. The "high" builds up over Canada, for example. The cold front rushes down to Texas, while the peak of the high may not have reached our border. The cyclone wave forms along the cold front. The cyclone grows, pushing over the cold air to the northeast and pursued by the cold air on the northwest. There is a chance for confusion here. The anticyclone wind immediately behind the cold front is considered the rear half of the cyclone. But the northwestern part of the colder area is little affected by the cyclone's whirl, and lags. It may even remain nearly stationary and grow and sit in majestic control of a continent's weather.

The proudest, highest, coldest, densest anticyclone begins to dissipate at last because of its very virtues. The clear skies at its center invite the sun to warm the earth and weather it away. Its weight causes it to spread out to the seas where the heating from the sun and the warmer water inaugurate turbulence. Moving south and east it loses connection with the frigid conditions of its birth, and its subsidence breaks the pipe-line, so to speak, with the cold air aloft. It becomes merely a coolness, a transitory heave of pressure, another death in the tropics.

CHAPTER 9

The Cloud as Forecaster

THE FOREGOING chapters have outlined the structure of the weather. Weather is air at work, and a forecaster keeps these basic principles of the air's actions always in the back of his mind. The procedures so far discussed have been largely invisible, accessible only to instruments. But now we are ready to take up the more intimate phases of the weather's activities. This is where one's eyes come in. Weather, of course, does its own forecasting. It only remains for us to read what is written in the sky, and of all the signs in the heavens, the cloud is the most legible.

A cloud is the commonest sight in nature. Parts of this earth never see the sun for weeks at a time. Other parts have no grass, no water. But there is no sky that does not have its cloud at times. So it seems strange that so few people are interested enough in clouds to know their names or significance. It was not until 1803—A.D. not B.C.—that a man first ventured to classify the clouds. His name was Luke Howard, and the great Goethe, the wisest man in Europe, was so astounded by this achievement that he wrote a poem to that Englishman.

To any road-wandering weather-lover, this hoorah is incomprehensible. It is like knighting some Doctor of Philosophy for discovering that some days are rainy and some aren't. What did people do with their eyes before 1803? Sorting the clouds seems an easy way to start an epoch, yet Luke Howard's essay *On the Modification of Clouds* did just

that. After pondering this feat for 93 more years, scientists organized a systematic world-wide study of clouds for a romantic twelvemonth which was known as the International Cloud Year. This in turn gave rise to an international system of cloud classification. For a nickel the Superintendent of Documents, Washington, D. C., will send a sheet of cloud forms prepared according to this system. Its 20 photographs and definitions derived from the "International Atlas of Clouds and of States of the Sky" are worth having. But the great, and often exciting, moving-picture remains in the sky.

Cloud is the middle stage in the life cycle of a unit of water. In its pre-natal state it is simply moist air that has not reached the dewpoint and so has not condensed into visible water droplets. In its dying state it is precipitation. In between it is fog if in touch with the ground and cloud when it takes to the air. There are ten tribes of clouds; each tribe has several members, and each member is a fortune-teller in its own sphere. To the gross gaze, clouds, like fortune-tellers here below, are not always perfect in their predictions. Yet a fond scrutiny of their continuous changes would prove the error in the gazer. A cloud is a living thing, sensitive to every variation in temperature, humidity, and pressure, and those who know the code in which it signals can read what is going on simultaneously in different levels of the atmosphere.

Luke Howard found four kinds of clouds to be universal: cirrus, stratus, cumulus, nimbus. Modern cloud-splitting enthusiasts now roll out a dozen sonorous Latin descriptives for the cumulus alone. Yet one wouldn't be doing ill by a child to teach him simply the four main sorts, or even three: the high-layer clouds (cirrus, cirrostratus, cirrocumulus, altostratus, and altocumulus), the low-layer clouds (stratus, nimbostratus), and the clouds of vertical growth (cumulus, cumulonimbus). The cloud-knower must have the aptitudes of a good chef. He must be aware that it is the nuances, the

combinations, the pinch of this and dash of that, that matter. The least important thing about a cloud is its name. Perhaps that is why the world waited so patiently until 1803 for Mr. Howard.

The cirrus family are the high fliers. They speed at levels ranging from 10,000 to 30,000 feet at 200 miles an hour. When the first flakes of snow falling on a macadam road are swept by the breeze of a passing car, the bright dust forms swirls and streamers. The same figures appear in the upper heavens on the highways of the prevailing westerlies. They too are a flow of ice crystals, thin enough not to cast a shadow on lower clouds or dim the sun when crossing its disc.

Cirrus is a detached cloud, and when it first appears in an arrowy rush against the flawless blue of an anticyclone sky it takes shapes of thrilling beauty. These arcs and plumes are the wafts of vapor cast up by a cyclone perhaps a thousand miles to the southwest and borne ahead faster than storm can travel. No sign in weather carries more weight than this feathery phrase, "Storm coming," if it is followed by an increase in sky coverage growing denser westward. A few strands have small significance. In dry weather all signs are supposed to fail; but the dry weather is itself a sign bidding one be more alert. In the droughty fall of 1941 the noon skies were magnificent for weeks with strands of cirri. They looked like combings from the white tail of that fabled stallion, Pegasus; yet no storm came. Lows passed to the far north and the far south, but the great controls denied rain. The cirri were reproached for lying but the experienced observer noted that their flags were not confirmed by cirrocumulus or cirrostratus, so what they said was not important.

The cirrocumulus is a field of cloud flakes, rounded tufts of cloud comparatively shadowless and small. They form patterns in groups or lines, often like ripples of seashore sand. When the sun shines through a vast expanse of this dappled

cloud, the effect is of symmetry vying with variety. The fleecy coverlet may be made of 50,000 cloudlets each dispelling an exquisite luminousness. It is caused by innumerable convective rises of air with equivalent falls. It too has an altitude range of between 10,000 and 30,000 feet. As it shows activity it has inspired that delightfully evasive proverb, "Mackerel sky, soon wet or soon dry." If it is to be "soon wet," this cirrocumulus can be seen deepening into cirrostratus.

Cirrostratus is the thin white veil that confirms the cirrus' prophecy of storm. At first it is the merest diffusion of cloud, dimming the blue but failing to prevent tree shadows on the ground or blurring outline of sun or moon, although it does give rise to wide halos. As it deepens in density it may show a fibrous texture. Its undersurface is not so high as cirrus. It is composed of ice crystals, even in summer, and is caused by forced convection to great altitudes.

None of the cirrus clouds give fliers trouble, by either icing, precipitation or turbulence.

The alto clouds, altocumulus and altostratus, have a lower range, from 6,000 to 20,000 feet. They are composed of water droplets, usually, rather than of ice crystals, and so can give trouble to aircraft. There is no turbulence in altostratus to speak of, but mild or even moderate in altocumulus. Icing is likely, although it may be mild to moderate.

Altocumulus takes the same forms of detached fleecy cloud as cirrocumulus, but the layer is lower, the cloudlets are larger, and their thin translucent edges often show an irisation that is characteristic. They too are arranged in closely packed rows. A shower from these clouds is possible, especially when the cloud sheet is continuous over much of the layer, and dark. It assumes a castellated effect, as of cumuli in miniature, and this altostratus castellatus warns of a change to a confused and thundery sky. Sometimes the alto-

cumulus is as small and fine as cirrocumulus, but it gives itself away by the observer's finding larger cloudlets elsewhere in the same layer, and by its grayer color. Also cirrocumulus is always or almost always connected with cirrus or cirrostratus.

Altostratus is sometimes like a heavy cirrostratus, lower in the sky, and through it the shape of sun or moon can be seen but rather as in a cocoon than in a halo-house. Altostratus oftener is a thick dense sheet bluing with density and hiding sun and moon. Differences of thickness may cause variations of shading, but the undersurfaces of altostratus never show sharp relief. A steadily deepening altostratus is an almost certain sign of protracted precipitation. If this is to be snow, the even gray merely looks heavier; but if rain, indistinct and darker clouds are likely to form beneath the even field.

The stratus clouds proper really get down to business. They are encountered at the 1000 to 6000-foot levels, with the nimbostratus as low as 100 feet. Their turbulence is mild, and their icing is usually light, or at most moderate. They are oftenest composed of water droplets, and to rain (or snow) is their mission.

Stratocumulus is the roll cloud, and its elements are regularly arranged, with flat bases at the same height. They are larger than altocumulus, soft and gray with darker parts. But just as often they form a low continuous sheet with distinct irregularities of large size. The edges join, covering the sky with a wavy appearance. The prescribed way to tell whether the patterned parts are altocumulus or stratocumulus is to extend the arm, and if the cloud unit is covered by the width of three fingers, it is altocumulus; if greater than this rough estimate of ten solar diameters, it is stratocumulus. From darker portions showers can be expected, or snowflurries. They are threateners, however, oftener than per-

formers, rather shallow on the average, and make a confused sky. The name covers the whole range of clouds between straight stratus and distinct cumuli.

Stratus is the dullest cloud of all. It is a low uniform layer, as featureless as fog but not resting on the ground. Its rain is likely to be small or simply a drizzle. It merges often with nimbostratus.

Nimbostratus (Luke Howard's nimbus) is the thick extensive layer of uniform cloud from which rain or snow is falling or about to fall. The average altitude of its undersurface is about 3000 feet. A layer of altostratus has thickened and lowered, often taking on a hazily ragged aspect. Experience and close watching can tell the consolidating moment (or half-hour) when the first flake or drop can be expected. During the storm, scud, looking like blown rags, flies across under the nimbostratus as low as tall trees. The precipitation from nimbostratus is likely to be long drawn out. But its dull dun pavement may flatten the sky overhead for hours or days after the precipitation ceases. This happens particularly over northern cities in late autumn or winter and occasions conversation printable only in novels.

The foregoing classes of clouds can be called horizontal clouds, even though convection is their cause. The cumulus family are of vertical growth. They range from the fair-weather clouds of summer afternoons to the towering thunderheads, and they are the airman's bogey.

The cumulus formation beautifies everything it touches. There are as many variations on this cumulus theme as on one of Haydn's. The theme itself is simple. An expanse of sun-warmed ground heats the air above it until the column rises and reaches the dewpoint. The cloud particles form quickly, fluffy as steam and as billowy. As the saturation level is likely to be uniform, the bases of the young cumuli appear level. Their tops are limited by the floor of some

inhospitable colder current. The velocity of ascent carries the tops of some of the air fountains into this obstructive layer, and we see small domes of arrested vapor materializing. The rounded turmoil is sun-edged and glistening. We who live in the cellar of the atmosphere have only glimpses of the total magnificence. The airman gets the view. But all these rising columns of air make the going bumpy for planes, and his aesthetic delight is tempered by their turbulence.

The cumulus cloud passes through three distinct stages. Cumulus humilis is the white and harmless fluff just described. It never outlives its youth. It sheds no rain or hail, breeds no gusty winds, and disappears in the late afternoon when the sun no longer raises geysers of warm air. At its largest it covers less than half the sky and holds no lightning. It may occasion a moderate roughness within it or underneath. It is as eloquent as a radiogram of what is to be. If it forms early in the forenoon and keeps on growing, it must be watched more closely, for there is always a threat in its ivory heart.

Cumulus congestus is the middle stage between humilis and thunderstorm. Congestus can frequently be seen growing. The vertical air thrusts become vertical rivers of warm air boiling upward at great velocity. Bulges protrude above, the base broadens and darkens. The flier finds rough going underneath and very rough within. But no hail as yet, no lightning, and only in its maturest stage any rain. Congestus is not yet a thunderstorm. It may be cut off from its source of vigor by floating from above the place that fed it heated air. Or it may be dwarfed too soon above. Its top will tell. Its top must find frigidity or there will be no development into cumulonimbus. But the moment that freezing is reached, the moment the rounded and defined outlines of its summits smooth away into one polar milkiness, congestus is adult. Cumulus congestus must have ice on his brow to form fire in

his heart and rain in his veins and issue his first voice of thunder.

Cumulonimbus is grandeur beyond computation. It builds into Himalayan ranges whose summits transcend Everest's and whose gorges dwarf the Grand Canyon to a gutter. Yet, funny race that we are, we dismiss these marvels of the invisible genies, water and heat, with a glance and then travel across the oceans to view them in lesser forms. A great thunder pile towering to the top of the troposphere above the summer snowline into regions of wintry hurricane spans the breadth of the seasons—at its base the super-tropical heat of our July, at its peak arctic January. This is architecture of the gods. The gale blows the snow of its icy eaves into strands of thunder-cirrus miles through space. Occasionally the up-hurtling air flattens against some obdurate if invisible ceiling and the cloud takes a strangely threatening anvil shape. On such an anvil Homer gazed and pictured the still more ancient Jove fashioning his thunderbolts. It is one of nature's paradoxes that our sultriest violence-laden storm requires the cool gentleness of snow to make that violence possible. The supernal chaos of the cumulonimbus will be discussed in the chapter on thunderstorms.

Everything about a cloud is prophetic—its shape, color, size, altitude, rate of growth or decrease, time of appearing, change of texture, the quadrant of sky in which it moves or rests, the fraction of the sky it covers (and this cloud scale has import), the company it keeps, its speed, ancestry, and correlative circumstances. If clouds had tongues, I think they would cry Shame on us unobservant mortals. Clouds are perhaps nature's crowning glory, and how often can we spare five minutes for them unless it be for some gaudier sunset? Clouds went out when cities came in, for clouds are best seen when lying on one's back, and that would excite comment in a city. When we walked on all fours we doubtless saw fewer

clouds than now but we are still far from the birds in that ability, although we can outfly them and look down on eagles. Our great brows are in the way. Necks hurt. Yet there, overhead, is the supreme moving-picture, ever-changing, and that rapidly enough to suit even us. Cirrus clouds in winter move faster than 100 feet a second.

Forecasting by clouds is helped out by high hills or mountains. When peaks put on their nightcaps the weather is changing for the wetter. And if the cloud level is rising on the slopes, it will be clearing and colder. Sometimes a summit will wear a cloud banner that evaporates as fast at its end as it forms to the leeward of the peak. The pressure next the rock has been reduced by a strong wind and a lower temperature results, thus making the local condensation. Similarly lenticular clouds may be observed lying like whales asleep. This sort of stratus cloud betokens the colder crest of some air billow that is condensing as it nears a mountain range. The atmosphere can be as billowy as any sea, as a whole overcast of windrow clouds attest. A fog sheet is often windrowed on top, but without the intervening strips of clearness that the higher windrow clouds show. When snow or hail forms in the upper levels of a thunderhead, the cooler parcels of air descend and make festoons of sagging vapor. Look aloft after some severe thunderstorm, with an aftersheet of high cloud not obscured by rain, and you may see this cloud called mammatocumulus. It is like a vast gray-blue hammock on which hundreds of cherubs are sitting, but one sees only the bulges in the vapor.

When clouds move in different directions at two or three levels, look for storm. The topmost stratum may be cirrus coming from the west, and hardly counts. But if there be a float of cumulus from the south and perhaps a light drift of vapor from the east, there are collisions of air currents imminent and almost inevitable precipitation.

In winter dark hard clouds betoken a bleak wind. When clouds bank along a horizon when they should be moving along, it is a sign of a major wind-shift. Clouds are riders all. They illustrate with pictures what the wind has said first. This elusive element we shall now look into.

CHAPTER 10

The Winds

THE WINDS form the transportation system of the atmosphere. Sixteen million tons of water fall upon this planet every second. (While I was writing that, 30 million tons fell.) And every droplet of vapor in that stupendous freight had been borne from its sea source to destination by the winds. Without them this earth would be a sorry desert.

In terser textbooks wind is defined as air in motion. It is air that has been put in motion in spite of that inertia which Einstein ranks as heaven's first law, order coming second. Wind has been coerced into motion by gravity and the differential of pressures. When you feel wind on your face, you may know that you have interrupted a parcel of air en route somewhere to keep a barometric appointment. When the air is very late, houses have to get out of the way.

The transportation system works most smoothly aloft. The great westerlies stream along with considerable steadiness, although even near the stratosphere there is some wave motion on a grand scale. The curves and convolutions of the cirri show that.

But below an altitude of 600 feet the wind proceeds in an unpicturable turmoil. Friction with field and wood and hill forms an irregular drag upon its undermost layer. The over layers stub their toes, stumble forward, fall down, turn somersaults, make mill-wheels, make spinners, fluctuate in velocity, rush and crowd and pick themselves up and go on. Stand on a woodland road some March noon and listen. The effect is of

express trains roaring by on separate tracks. In the lull after one limited has breezed past, you can hear another a quarter of a mile away. A train of wind may be a mile long and an eighth of a mile wide, and within it are as many puffs, gusts, swirls, directions, and dog-fights of air parcels, as there would be passengers on a wartime express.

The vertical convulsions of wind are less rapid but just as intricate. Watch the blue ribbon rising from a lighted cigarette. Magnify those spirals and scrolls and writhing patterns, multiply their speed, and you have a view of the winds within a thundercloud. Air is a sensitive thing, and seems flimsy until it gets force behind it, when it will perform prodigies incomprehensible.

The flier has to contend with these gyrations of the invisible. Picture a bird flying over a geyser field in Yellowstone Park, unable to see the geysers. If its wing cuts into the uprushing fountain, its stability is upset laterally. And so with the airman whose plane slices into the sharply defined side of an air column rising from a plowed field. Or suppose the bird dashes head on into Old Faithful. Its angle of ascent is raised abruptly. Or suddenly it emerges into quieter air and a sudden falling-off occurs. Complicate this rising column with rotation, and adjustment is needed. The new pilot is tempted to overadjust. The experienced pilot utilizes these gushers in climbing. The modern heavy plane is not much affected, one must admit, by this roughness unless it is very considerable. In localities with pronounced variations in convectional risk, the jolting can be excessive.

The air in the neighborhood of a convection column is likely to be sinking. The flier soars out over spots of comparative chill, such as cold lakes or offshore regions, on a warm day, and is liable to sink with it, even abruptly.

Mountainsides and precipices emphasize this tendency. If the mountainsides are bare, the cold dense air from above

gains momentum as its down-rush meets no obstacle and the airman suddenly is overwhelmed by a Niagara. If the cold air is additionally heavy with snow, it can reach strong velocities on the lee sides of mountains. The same down-tendency can occur at the edges of clear-cut clouds. If these are cumuli, the air is flying up, often at immense speed, within the cloud and down in the clear. The thing is to steer away from a stratum of broken cloud; the very shape of it denotes turbulence.

Similarly with ridges. If a strong wind is storming a mountain ridge, the down-sweep of air on the lee side may be so pronounced as to persuade the pilot he has fallen into an air-pocket. In passing from one terrain to another, the airman has always a hint of the nature of the conforming air.

But in transfer from one wind layer to another he has no advance warning unless by clouds. The lift of his plane is approximately proportional to the square of the velocity of the plane with reference to the air in which he is advancing. And the wind's pressure is proportional to the square of its velocity. Consequently a plane, at least when gliding, loses some, and even much, of its supporting force when it runs from a cold dense layer of air into a warm and less dense layer. Wind occurs in layers oftenest when good weather is changing to disturbed. One layer overlaps another.

As this overlapping of one density by another takes place, great billows are formed, just as by wind over water. By keeping within the one layer, a flier can find smooth going, while above or below he may have to ride the billows. Sometimes these are large enough to make noticeable pressure changes on a barograph.

When the flier turns he finds out how marked the gusts, caused by horizontal winds meeting obstructions, can be. Everyone has noticed the turmoil in the top of a tall tree when a gust passes. It can be seen that a banking plane's wing,

encountering wind of different velocity from the wind above, may be endangered by the unexpected. Eddies occur in the wind when obstacles divert the direction of its flow. Their whirl increases with the wind's velocity. In wind, the eddy can be horizontal as well as vertical. If horizontal, the greatest downward thrust occurs at its forward side.

The squall lines of cold fronts and of thunderstorms occasion violent confusion of air direction and change of speeds. A tidal wave on a seashore is a safe and stately affair as compared with the windshift line of a well-developed cyclone. This condition gives its warning, however, and the flier can either surmount it at high altitude or stay grounded.

Wind, as should be obvious by now, is too smooth a word for wind. And similarly it is misleading to think of wind as speed. It is force, and this force is indicated by the square of the speed. A wind of 20 miles an hour creates a pressure in pounds for every square foot of surface against which it is blowing at right angles 4 times as great as the wind of 10 miles per hour. A wind at 30 miles is 9 times as powerful as the wind at 10. And a hurricane wind of 120 miles per hour throws itself with 144 times the impact of the 10-mile wind. So the air age which is counting upon using the upper westerlies which flow along at 200 miles an hour had better be sure of its directions. It will be no fun bucking a wind 400 times as strong as a 10-mile wind.

Apparently our unscientifically minded ancestors cared little for scales. It wasn't until 1805 that Admiral Beaufort brought out his scale of wind speeds, now internationally used. Before that, people slid adjectives around instead of fastening them to certain velocities. In Defoe's *The Storm*, it is true, Robinson Crusoe's creator did try to fix winds into a progression of speeds—"stark calm, calm weather, little wind, a fine breeze, a small gale, a topsail gale, blows fresh, a hard gale of wind, a fret of wind, a storm, a tempest." But "a fret

of wind" for a 60-mile gale hits the funny bone. The Admiral's ladder runs: "calm, light air, slight breeze, moderate breeze, fresh breeze, strong breeze, moderate gale, fresh gale, strong gale, whole gale, storm, hurricane." (Cf. Appendix for Beaufort Scale.) Even this nomenclature, with terms prescribed by our Weather Bureau, might have been improved. The four kinds of breezes confuse the layman eager to speak accurately, when quarter breeze, half breeze, three-quarter breeze, and whole breeze, while less picturesque, would state the relative strengths. Also "storm" seems as much anticlimax as the Crusonian "fret of wind" after a hard gale or a whole one.

Further invention has to be carried out before the speed of wind is measured satisfactorily. The fluctuations are too rapid to be easily recorded, and the difficulty of being in the right place with a strong enough instrument has left the hurricane velocities largely unknown. In the New England hurricane of 1938, the maximum wind for a 5-minute period was at the rate of 121 miles per hour, with one gust of 183 miles per hour, at Blue Hill Observatory, Milton, Mass. But that hurricane was far from its tropic home. What must happen in the savagest fury of a great hurricane is left to the imagination. Tornadoes develop in some hurricanes, and the speed of a tornado's wind is estimated at 500 miles per hour. But nobody knows. On Mt. Washington a gust of 231 miles per hour has been recorded.

To judge from our vocabularies, wind is the element that has made the most impression on our race. In Kraght's *Meteorology for Ship and Aircraft Operation*, there are eighty terms listed in his "Glossary of Winds." Of the eighteen chapters in the weather section of Humphreys' *Physics of the Air*, seven deal with the wind. The observer instinctively assures himself of the wind's direction. It is all-important. Clouds may deceive, wind practically never.

Nature loves paradoxes, and her most successful is the fact that the least stable element is the most reliable guide. Of course each section of the country has its pet winds, the direction giving it the most salubrious weather. Winds acquire individuality in the course of living with them, and are complimented or reviled according to the gifts they bring.

The west wind would rate highest in a country-wide poll. It is the temperate feature of our Temperate Zone. Its somewhat descending current clears the sky, tempers the summer heat, adds the cheerfulness of sun to the winter's cold. It has made more poem anthologies than any other wind. It is extremely dull.

A northwest wind is livelier. It brings a more intense cold in winter and an energetic clarity in summer. Whatever is said about the west winds must add footnotes for places east of water. To the leeward of the Great Lakes, the west and northwest winds bring a moody cloudiness consequent to the perpetual steaming and condensation of those big tubs. On the Pacific coast, and the Gulf coast of Florida, west winds are also moisture-laden.

The north wind can be simon pure frigidity. Its vitality differs with place. To the Great Plains and to Texas, the northers bring violent gales, fog-thick with snow, with drops of 50° in temperature, the true blizzard. In the East a north wind is usually the waning stage of a northwest wind, and rarely strong. Coming at the end of a cold spell, it inherits the accumulation of chill and marks up the records that people talk about. It brings the quintessence of winter, a calm when the stars shine hard and bright. In the morning the wind will perhaps be but a breath of air from north-northeast, and a new cycle of weather starts.

The east wind is the surest moisture-bringer for most of our land. Even in summer it can be clammy, and in winter

raw and chilly. Although we still bear the salinity of our sea-ancestors in our blood, we have lost our taste for dampness. The east winds do not figure in anthologies. Yet rain is the best of lullabies and a winter nor'easter gladdens skidom's heart. The long, dependable snowstorms come on a northeast wind, the drenching rains on a southeaster. The Great Lakes, the Atlantic, the Gulf of Mexico, form a wet semicircle from which the well-developed depressions can suck vapor. It is hard for us who look at the map as a collection of states, with boundaries, to visualize the immense sweeps of winds. A large storm feels confined in the United States.

South winds receive some flattery that is not their due. In winter a south wind ends a cold spell and brings the damp of thaw, which is worse. It finishes off the anticyclone and the sunshine at the same time. In summer it increases the humidity in the East and the drought over the Great Plains. Iowa can burn to a crisp under this poetic visitation. The south wind does, however, provide those most queenly clouds, the soft drifting masses that dissolve in showers. The southwest wind is gentler, also, than southeast or northwest winds. The ratio by average goes: SW 20, SE 30, NW 30, NE 16 miles per hour.

The observer is told more, perhaps, by the wind-shift than by the wind itself. A winter wind may have held for hours in the northeast with snow falling steadily and the temperature rising slightly as the storm center nears. A slight veering to ENE indicates that the next shift will be to the E, then ESE, SE, SSE, S, with a major increase in temperature, sleet, and rain. But if this NE wind back ever so little to NNE, the center is passing south of the observer, instead of to the north, the temperature will fall, the snow will not turn to rain although it will slacken and stop soon after the wind has got to some point west of north.

The wind's steadiness is another important footnote to

one's predictions. A fitful wind like a restless person provides uncertainty. A high northwest wind arrives with vigor enough to promise two or three days more of clear sky and slowly diminishing force. Suddenly, that is within a few hours, it drops, lulls, shows a tendency to shift. The meaning is that a cyclone, a secondary one, has developed quickly and its cirrus clouds are probably already in some quarter of the western sky. When wind curtails its usual program, something interesting is about to happen, and a check-up on the barometer may give the next clue.

A calm is the weather's waiting-room. A new round of weather is about to begin. All the old accounts are in and everything balances. There are several sorts of calms. At sunset, on a clear day, the forces of convection and gravity cancel out, perhaps only for a few moments, and no wind blows. Along the seashore, the same sort of cancellation occurs when the land breeze and sea breeze influences are equally weighted. If these truces are violated, it is a sign that a cyclone or an anticyclone has the ascendency.

A longer calm arrives, most noticeably in winter, when an aged and sluggish anticyclone stagnates. A condition of windlessness, except for a mild drift of air at noon and another at night, will continue for days. No cloud forms. Night temperatures plummet. The great white North lies in a cathedral-like silence beneath the silent moon. These seasons of atmospheric stillness are full repayment for the austerities of the other whiles. In our zone a lesser period transpires at times. We call it a "weather breeder."

The longest calms of all take place during the great transition from summer to winter, the autumnal truce called Indian Summer, the chief claim of American weather to fame. On these occasions a great immobilized high controls the south. Cyclones are shunted to sea, and a vast brooding quiet sleeps over half a continent. There is no Indian Spring

because the heating up of the land creates a turbulence that the autumnal cooling off allays. It is in March that the wind checks off the greatest mileage of any month.

The day's-end calm and the calm of summer's exhaustion imply continued fair, but the most dramatic calm in the repertory, "the eye of the hurricane" is comparable only to the breathless pause at a hanging before the hangman springs the trap. The unfortunates caught in that calm can count the minutes before the violent winds leap at them from a new quarter. The other spectacular calm, that foreboding ten-count wait before the knockout blow of a thunderstorm, never calmed anybody. It is pure excitement.

CHAPTER 11

Temperatures

TEMPERATURE is probably the most interesting datum of the weather to many people. "How cold did it get down your way?" is a normal rural greeting. An extreme in temperature is treated as a collector's item, like a rare stamp or a beautifully worm-eaten antique. Meteorologists linger lovingly over the 90.4° below zero registered at Verkhoyansk, Siberia, on February 5, 1892, and again on February 7, just to show that the feat could be repeated. They like to report the 136° recorded at Azizia, Libya, on September 13, 1922, a place that sounds as if it had been named after that sizzling event. It is human nature to hope that these records will be broken. There is nobody more imaginative than a scientist.

The forecaster, however, is concerned with the temperatures of the present and of the immediate future. The thermometer, like the barometer, can state only one fact at a time, but its trend is full of meaning.

The amazing thing about this earth's temperatures is their scant range. The sun's surface temperature is conceded to be about 11,000° F. The temperature of space is 459° F. below zero. Yet the difference between the greatest extremes so far recorded in nature on this planet is only 226.4° as against that possible 11,459°, and this paltry 226.4° far exceeds anything that we are called upon to bear. Only twice in a decade does the temperature vary as much as 60° in 24 hours, and there are vast areas where the daily change amounts to only a few degrees. However, people like to con-

sider themselves perishable, like fruit, and it is the forecaster's duty to warn them in advance of any change in temperature, no matter how slight.

To predict temperatures wisely, the amateur without a map to rely upon must sharpen his wits on the winds and clouds. Certain generalizations become part of his assurance: that winds from a little north of west around to a little north of east are cooler, colder, than from the remaining points of the compass; that temperature will rise before a storm, but more conspicuously in winter, with exceptions, under conditions when the heat of the storm is less than that of the sun's rays intercepted by the clouds.

He will note that the rate of change from fair weather to the period of precipitation controls the rise rate of temperature; that a veering wind (east to west via the south) brings greater changes than a backing wind (east to west via the north), because in the latter instance the warm sector is passing south of the observer whose locality, therefore, cannot participate in the full temperature range of the storm cycle.

He will note that the greater the intensity of the storm, the greater the cold to follow, and if the fall in temperature is lacking in proportion, something out of the normal sequence is about to happen; the period of fair weather to be expected will be curtailed, or one of those seasonable step-ups—as from winter to spring—is in progress. After a thunderstorm this change to cooler should occur; if it doesn't, another thunderstorm.

He will beware of any interruption to the normal progress of temperature which should register coolest at dawn or shortly after, warmest an hour or two or three after noon. The forecaster who finds his thermometer higher at breakfast than at bedtime does not have to look at the sky; he knows that it is cloudy. Cloud is more than a blanket in

winter; it is eiderdown. It is astonishing how much heat a cloud can keep from radiating through a night. A normal winter anticyclone night in the inland north can find the thermometer at 15° F. above zero at 8 P.M., 5° above at midnight, 5° below at 4 A.M., 15° below at 8 A.M., dipping 3 or 4 degrees just after sunrise, then slowly climbing until an hour after sunrise, after which the climb is faster until an hour or so after noon. But if the mercury stays at the same level during the sunny hours, the next night will be considerably colder. These figures are relative, of course, and non-duplicating for, like snowflakes, no two temperature graphs are just alike. Nor does this imaginary progress indicate any of the inversions that are likely to occur on such a night. Often the ground chills the surface air much faster than the air a little above the surface, and instead of the normal adiabatic rate of decrease there will be a stratum of warmer air above. This condition makes for great stability, and the temperature graph may decline very slowly for several hours. Then as the upper air chills, the graph will decline at a normal rate of speed or even faster than normal. When one admits that there is no normal, he has said everything. Only experience will tell the forecaster what is likely to happen on this average simple night.

The forecaster with a weather map, on the other hand, has far less excuse for not knowing what the morrow's temperature will be. The map informs him of the two great influences on temperature—the areas of high and low pressure. Its isobars warn him of the intensity of these influences and their speed of approach. Its isotherms, not drawn in, to be sure, but obvious from the figures, picture the temperatures experienced by places in the same barometric plight as his locality. A dotted line gives him the position of the freezing line across the country, and another shows how far south the zero line has intruded. Past experience has shown him what tempera-

ture relations his locality bears to the localities on the map. A thousand other maps—only three years of interested inspection—have convinced him that if it is such-and-such a temperature at Buffalo, Chicago, Kansas City, Duluth, and Bismarck, it will, other things being equal, be such-and-such at his place. He knows that a cold wave entering the country to the north of him is going to be far more frigid than one that enters considerably farther west. He knows what a stagnant low to the northwest of him will do in summer; it will fry the very worms on the fairway. He knows that there are two temperature controls, local and countrywide, and his thermometer registers a series of compromises. A stretch of forest, a lake, nearness to the coast, a range of hills, not to say mountains, all make variations on the given theme.

It is one of the duties of Weather Bureau forecasters to include in the daily forecast a definite temperature prediction. The average of accuracy is astonishing to anyone who has tried his hand at it, if not to the casual noter of the mistakes. Any stock-market trader who could guess the daily fluctuations of United States Steel with similar accuracy would die wealthy and respected.

Map-students find frequent variations of rhythm in pressure changes. A succession of quick-moving highs and lows with rapidly alternating extremes of cold and heat will be followed by a sluggish period, and it is in these arrested pressure areas that the truly notable records are made. Late in December, 1935, a cold period began for Kansas, Missouri, the Ohio River region, and points north, which lasted into March. At Langdon, N. Dak., it was zero or below for 67 consecutive nights. From January 18 to February 22 it was 20° below zero, or colder. On February 16 it reached 51° below. The several million residents of this section unanimously ceased to complain of the absence of old-fashioned winters.

June, July, and August of 1934 had treated many of the same people to a heat period which put the tropics to shame. At Emporia, Kans., there were 64 days with maximum temperatures of 100° or higher, 27 days with a maximum of 110° or higher, and one day when the Government thermometer registered 116°. Temperatures in the sun must have been considerably higher.

These periods of extremes are brought about by the Atlantic "high," the permanent belt of high pressure lying just north of the Tropic of Cancer and extending across the ocean. When its crest moves eastward, toward the Azores, pressures diminish in our southeastern states and the gradient favors an influx of cold air from Canada. This results in abnormally low temperatures from the Rocky Mountains eastward. But if the crest moves westward, the reverse gradient favors a flow of tropic air northward, and almost intolerable temperatures obtain over much of the country. Of course, if these dislocations are out of step with the seasons, causing cooler summers and milder winters, people rejoice. But when the movement synchronizes with the seasons, enhancing cold or heat, the record-breaking periods result. If other influences were not also present, long-range forecasting from the position of the Atlantic high would be profitable.

Temperature is like a person's disposition: it affects every moment of the weather-day. It plays with fliers' lives on the fog level, the thunderstorm level, the icing level. It can clear the skies or cloud them. The weather-seeker with access only to surface temperatures gets about as much of the story as the reader who skims only the first line on each page of this book. The radiosonde is one of the instruments of the future, and the amateur forecaster will undoubtedly be supplied with the higher level figures as he now is with the temperature of a few cities.

CHAPTER 12

Rain

THE RAIN that falls alike on those who expected it and those who didn't is only now being understood. The life-history of a raindrop is one of the fascinating stories of nature. Nothing would seem more commonplace, nothing less likely to precipitate pages of equations. Yet if you think that, you don't know your raindrop, nor your scientist.

The ancient and understandable notion of rain was that it arrived from afar in a ready-to-pour condition. The cloud was thought of as a waterpot which, for some reason, spilled overhead. A little study, after the race had learned to observe, corrected this view. It was found that rain was made fresh on the spot. Its cause was a moist parcel of air and a fall of temperature. For untold ages pitchers of ice-water had been making it rain before people's eyes on summer days. Now it was discovered that the same process went on overhead. The cloud was chilled beyond its dewpoint, condensation occurred, the drops got larger, and instead of running down the sides of a pitcher they fell through the cloud.

This would have satisfied most people, but a scientist is never content until he has resolved a simple thing into a mass of perplexities. It was found that every raindrop had to have a nucleus. They began to count, or at least compute, the number of nuclei available. Particles of dust were assigned to this duty, and there seemed to be enough. One good drag on a cigarette produced a billion particles and more. One active volcano—and remember the 325 of them currently

active—obviously could produce the equivalent of a hundred billion smokers. In fact, there was too much dust. If all the vapor in an air parcel laid hold of all the dust particles in it, there would not be enough vapor to form droplets larger than fog. And sometimes this happened. Sometimes a cloud would overcast the sky for days without yielding one good-sized raindrop. Why, then, did rain sometimes form and fall, and not at other times? And how?

Presently Lord Rayleigh observed that drops of water rebounded from one another unless electrified. This was owing to a film of air between them. It was seen, too, that drops large enough to fall to earth simply did not form in just any old cloud; and if they did form and fall, they would not touch enough other drops, no matter how well electrified, to make a medium-sized drop, to say nothing of the splashers in a heavy rain.

Yet, as Humphreys remarks in *Physics of the Air*, it does rain. Large drops do form. Either some of the hundred thousand nuclei in each cubic centimeter of air—a space of smaller dimensions than a lump of sugar—must be eliminated, or some process of enlarging droplets must be found.

Both things were done. Scientists looked more closely at dust particles and found that for the most part they were not hygroscopic, that is, not water-attracting. That threw out, as nuclei, most of the dust produced by volcanoes, meteors, deserts, and cigarette smokers. That was a blow. Since it rains sixteen million tons a second on the planet, and since every drop of rain in that staggering fall has to have a nucleus, where would these nuclei come from in such quantities if not from dust?

Ions, electrified particles in the atmosphere, were considered. They were everywhere and small enough, in all faith. Then it was found that a super-saturation of several hundred per cent would be required to get the ions working, and

such a state was impossible in our atmosphere. Yet it was still raining.

Finally the gases from fires were discovered to be one source of nuclei. Active combustion gives off sulphur dioxide, which changes to sulphur trioxide in the sunlight, and is a strong attracter of water, even when the relative humidity is low. But what of the vast reaches of the oceans where there were no forest fires, no chimney flues, no smokes of any sort—and still plenty of rain? What hygroscopic particles could be found in the middle of the Pacific in quantity to stock a typhoon with rain?

The only answer was salt. Salt was an ideal hygroscope. One part of salt could attract to itself 10,000 parts of water. It could begin collecting water when there was precious little of it in the air. A cloud droplet could be as small as 4/100 of a millimeter, and a millimeter is about 4/100 of an inch. Also there was salt and plenty. When ocean spray evaporated, as it was perpetually doing in unimaginable amounts all over the seven seas, it left microscopic particles of salt in the atmosphere. Convection was forever carrying this burden of nuclei aloft. The over-all circulation did the rest.

As convection lifted the salt-impregnated moist air, it was cooled adiabatically or by encountering some colder current, and as it passed its dewpoint countless cloud particles formed. Now these droplets, no matter how small, began to fall in respect to the air of their birth. This air, however, was rising into regions of fewer nuclei. It was thus twice filtered, by passing into nuclei-clear air and by the elimination of the nuclei already water-surrounded and falling. Therefore there were fewer nuclei on which the vapor in its vertical path could condense. Therefore these drops could grow larger and larger as a result of the progressive filtering and continuous condensation. It was discovered that, while waterdrops scattered by a hose jet rebounded because unelectrified, the drops pro-

duced by vertical convection became slightly electrified and did unite on collision.

The velocity of the rising air was also found to vary, giving the droplets alternate and repeated risings and fallings on their general descent to earth. By continuous condensation and coalescence with other electrified droplets, the drops at last became too large to be supported by the rising column and plummeted to earth.

There was still one major discovery to be made. Clouds tended to be colloidally stable, that is, in the lower temperatures when convection was absent, the droplets declined to coalesce. The electric charge of each droplet was too small to be thus effective. Motion was not enough, for often highly turbulent clouds did not produce precipitation. Nor was size a guarantee. What made it rain heavily in temperatures under 50° F? The answer was ice.

A condensation nucleus requires only 100 seconds to grow to a cloud droplet, but it takes the cloud droplet 24 hours to become raindrop size. Since no raindrop could be kept afloat that long, it was proved that coalescence rather than mere condensation must be depended upon. It is a curious thing that water droplets can be kept without freezing in cold storage, in temperatures below freezing. Airmen find water droplets in air as cold as zero F. This water is termed *supercooled* and it needs only a shaking, a disturbance of its colloidal stability, to solidify quickly. Now air that is saturated with respect to water is supersaturated with respect to ice. The moment an air mass contains both water and ice, the two different saturation pressures result in the water droplets evaporating and condensing on the ice particles. These become speedily heavier and fall, colliding with more water droplets on their way, and precipitation is released.

Ice, therefore, was found to be the key to coalescence and rainfall. As long as a cloud consisted of water droplets only,

it was stable colloidally, and this accounts for the long-continued cloud over the North Temperate Zone in the autumn. But when the cloud builds up at last to altitudes where some of the vapor at least is in the form of ice particles, the cloud becomes colloidally unstable, and precipitation begins.

Thus the innocent-seeming raindrop is a veteran first subjected to the processes of evaporation, then of convection, of condensation, of colloidal instability, and victorious gravity. A Norwegian named Bergeron built up this theory of a raindrop's release. It is substantiated by the fact that even the heavy summer rains come from clouds which are glaciated at the top. There is an exception in the showers, usually light, which come from clouds which do not reach up to any sub-freezing zone. But these clouds can contain drops with a temperature differential sufficiently great to produce a practical instability through turbulent mixing.

Rain has some poor relations: fog, a cloud of microscopically small droplets; mist, with drop .1 of a millimeter in diameter as against the .01 of fog; drizzle, with a drop twice the size of mist, a uniform precipitation from stratus cloud (or sometimes fog); light rain, with drops .45 mm. across, and not so numerous as drops in a drizzle. Light rain falls from higher sheets of cloud. Moderate rain falls at the rate of 4 millimeters an hour, heavy rain at 15 mm., excessive rain at 40 mm., and a cloudburst 100 mm. or over.

The severity of a rainstorm depends on the volume of moisture in the air, the rate and intensity of cooling, and the duration of the precipitation process. The greatest authenticated rains occur at Cherrapunji, India, where very warm air capable of holding great amounts of vapor evaporated from the Indian Ocean is driven up the slopes of the Himalayas with rapid cooling. Here everything happens on the grand scale—tropic air, tremendous saturation, sudden pre-

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STRATOCUMULUS OPACUS

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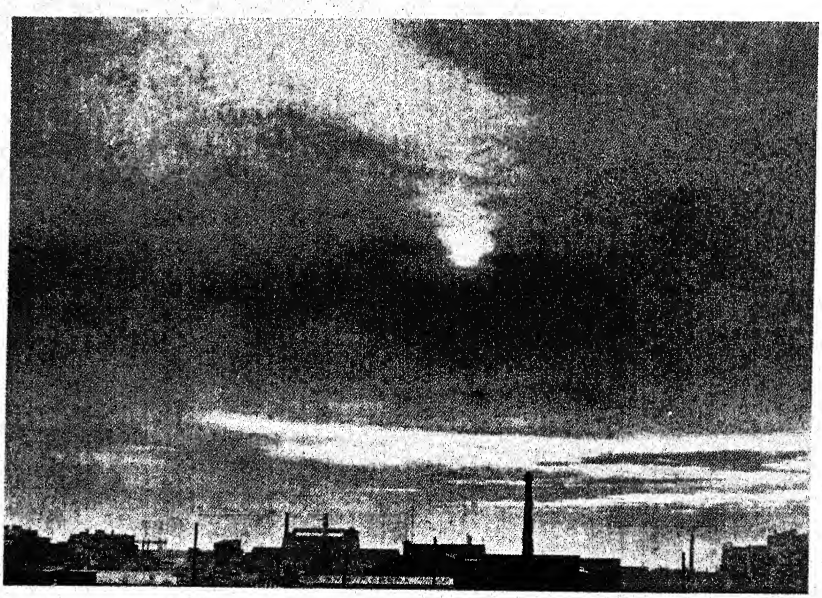
ALTOSTRATUS TRANSLUCIDUS



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ALTOSTRATUS OPACUS

cipitous ascents, incessant feeding in of this air by the monsoon. The results are unimaginable to our quiet kind who consider an inch of rain a day as a heavy storm, and an inch an hour something to remember. The *average* annual rainfall at Cherrapunji is 426 inches, most of which falls in the summer monsoon. It rained 241 inches in one August, and over 150 inches in 5 days. What is believed to be the world's record for a 24-hour rainfall is the 46 inches reported from Baguio, Luzon, Philippines, July 14–15, 1911, with 88 inches in 4 days. When rain gauges are perfected, greater amounts will be substituted for these understatements. The higher the wind the less accurate the catch, and in a hurricane not much more than 50% of the downpour is measured. Even so, a 24-hour fall of 23.22 inches occurred at New Smyrna, Fla., October 10–11, 1924. Persistence adds up. 23.22 is, after all, less than an inch an hour. At Opid's Camp, in California, during a shower, it rained 1.03 inches into a rain gauge in one minute, and .92 inches into another gauge 4 feet away. In Panama, in November, 1911, it rained 2.47 inches in 3 minutes.

Cloudbursts occur when hot wet air is suddenly cooled and the uprush of the convection column is so strong that the rain cannot struggle down to earth but is held up until for sheer weight it crashes. So terrific is the striking power of the descending water-bomb that great shell holes, wide and deep craters, are made in the ground by the impact, hillsides are torn away, and the country below is flooded. Journalists are paid, unfortunately, to spoil language. Any measurable snowstorm observed by a reporter is now a blizzard, any heavy shower a cloudburst. The penalty for so cheapening our vocabulary should be exposure to a real blizzard and a real cloudburst. Lazy reporting would soon be eliminated.

The United States is fortunate in its rainfall distribution. Its average annual precipitation is just under 29 inches. We

have our wet spots. A 13-year record at Wynoochee Oxbow, Wash., shows that that locality is provided with 150.73 inches of rain a year, and Louisiana is blessed with an annual average of 55.11 inches, making it our wettest state. We also have our dry spots. For a period of 5 years, 1909–1913, at Bagdad, Calif., the *total* fall was 3.93 inches, and the annual average at the Greenland Ranch is 1.35 inches. San Francisco gets 22 inches, Chicago 33 inches, New York City about 40 inches, as compared with London's 25 inches and Paris' 21. London's rain has soaked literature, while Chicago's greater rainfall rarely appears between stiff covers, because the nimbostratus usually sheds rain on London in small amounts and over long, if interrupted, periods, until it has become an institution. Of course London literature has been reporting considerably longer, too.

The combinations and permutations of the atmosphere leading to rain in our broad and varied country are as countless as the kinds of landscape. There is only one valid generalization: that all considerable precipitation comes from vertical-flowing air. This convection may be caused by the heating of surface areas, from converging winds in the forward half of a cyclone, a forced upflow over mountains or over under-running wedges of cooler air. Any observer must know his countryside. Its nearness to the sea or the Great Lakes or high country determines many of the conditions. Latitude, elevation, slope, surface cover—whether wooded, marshy, sandy, or snow-insulated—are factors regulating rainfall.

The two main sources of rain in the United States are the cyclone and the thunderstorm. The latter will have a chapter of its own. The sign-sequence leading to the rain of an extra-tropical cyclone is as routine as the courses of a hotel meal. Not long after an anticyclone has established cloudless skies and the northwest winds have diminished, the first high

white cirrus will be appearing from some westerly direction. Nothing is sure, is even probable, until the cirrus is followed by cirrostratus, either with or without a preceding mackerel sky or cirrocumulus or altocumulus. If the cirrostratus thickens until it has choked the sun, darkening to gray and blue, and lowering until it is altostratus, rain is almost certain. The rain of our north-of-the-Potomac latitude in the spring and fall comes from the altostratus layer.

Meanwhile the wind has shifted from the anticyclonic northwest to the easterly direction appropriate to the center. One can always tell where this center is to appear from by standing with one's back to the wind, stretching the left arm sidewise and then a little forward. If the wind backs, goes counter-clockwise, the center will be passing to the south; if the wind veers, it will be passing by way of north.

The most perplexing meteorological situation to the laity is the fact that a cyclone from the west is announced by an easterly wind. This paradox was first divined, as any American would expect, by Benjamin Franklin, who found that rainstorms traveled from Philadelphia to Boston in spite of the easterly wind apparently blowing them from Boston to Philadelphia.

A cyclone is similar to an eddy in a washbasin except that it is inverted. The air revolves, counter-clockwise, to the low-pressure center and is crowded upward. Visualize the eddy in a west-to-east moving stream. The center flows eastward but the air on the eastward side of the eddy is pouring in from the east. Expand the eddy to cover the whole eastern United States with its center at Pittsburgh and it is easy to see that the wind in Washington will be from the southeast, in New York from the east, in Albany from the northeast, in Buffalo from nearly north, in Chicago from the northwest. For the same reasons, the southeast quadrant of our cyclones is likely to be the wettest, as the air is sucked in from the Gulf

of Mexico, the South Atlantic, and the waters farther north progressively. On the Pacific coast, however, the heaviest rains are to the south and west of the center, since the moisture source lies to the west. In the region lying east of the Rockies with its pronounced upslope, precipitation is heaviest on the north since the convection caused by the raising of the cold air flowing south is more emphatic than that of thermal influences of the southeast quadrant.

Rain is the cyclone's child, but it can also occur when the anticyclone is too precipitate. A sudden cooling squeezes water from air. In the desert this can be seen to begin at high altitudes and the shower will be drunk by the drier air at lower levels before it touches ground.

Rain is humidity processed by cooling. The close observer, even if without instruments, has many clues to its coming. The general visibility, the lowering of clouds, the wind direction, the greater audibility of sounds, the actions of smoke, of birds—all are parts of the context. Sherlock Holmes must have been a keen weather forecaster, for he knew the value of exact observation of trifles.

CHAPTER 13

The Thunderstorm

THE ENTITY called a thunderstorm is unique in nature. It is constructed like a play. The first act introduces all the characters and foreshadows the plot. The second heightens the suspense and brings the crisis. The last resolves the sound and fury into a happy ending. The whole affair can be enjoyed at one sitting. It is the perfect matinee from which you emerge after thrilling drama into the late-afternoon sunshine and a cleansed air.

Until recently it was a mystery play. Nobody could account for the lightning, the thunder, the torrential rain, the excessive wind, all the tremendous forces conjured up on a serene summer day and vented in destruction. A thunderstorm did not sound as if it were keeping a secret, yet the secret was kept. Forty-four thousand thunderstorms a day had performed on the world stage for uncounted centuries, and nobody guessed that the electric charges of a raindrop were responsible. Then Simpson visited Simla, India, made electrical observations concerning rain during the monsoons, and science was ready to write program notes at last.

The genesis of a thunderstorm is in the convection of exceedingly unstable air. As this rises and condenses, it takes the form of a cumulus cloud. Within this tower of uprushing vapor there is a turbulence unknown in other clouds. The cloud pushes up into freezing temperatures and this glaciation produces rain. This rain is driven up by the furious upgusts with a velocity reaching 100 miles an hour, and the

drops grow in size. But when they reach a growth larger than 4 mm. in diameter, they are falling at a velocity of 8 meters a second and are shattered into smaller drops.

Now the tops and bottoms of raindrops are charged, oppositely, by the electric field of the earth. As a drop is shattered, the negative and positive electricity are separated. The smaller drops keep the positive charge but the air takes the negative. By repeated splittings of a tremendous number of drops, enormous charges of electricity accumulate. Since the negative-charged air ascends far faster than the breaking drops, it is clear that the positive charge will accumulate in the lower part of the cloud and the negative in the upper part of the ascending air.

Meanwhile a tension grows between the negatively charged earth and the electrified cloud. The tension continues to grow until a first small discharge starts from the cloud. This tentative discharge fades away in a brush, but is instantly followed by another and still another and others until a path is ionized, allowing a free flow of electricity progressively reaching from cloud to earth, whereupon there is a return surge of electricity of the opposite sign up this ionized trail.

This exchange happens with inconceivable rapidity. The elapsed time from the first faint pilot discharge followed by the series of leader discharges pushing ever faster and farther ahead and meeting the feeler discharge from the ground, is immeasurably brief. A single flash may last but a few millionths of a second. A multiple flash is over in a few hundredths of a second. What seems to the eye to be one glowing core of light is a succession of discharges. The brush merges into the spark, the spark into a streaming thunderbolt with a course from cloud to earth, occurring in an eye-blink, that may be miles long. Lightning from cloud to cloud pursues only a one-way course and, for all its river-like windings, may compass 10 or 15 miles of splendor.

Lightning occurs most often between the oppositely charged upper and lower zones of the cumulus cloud, its only home. This electrical separation is the mother of lightning. When a cloud becomes charged, lines of force exist between it and the earth, which is permanently charged. The dual strain is not wracking while these charges balance. Rain, however, is continually carrying down and adding its charge to the earth's. At the same time, wind is pulling the cloud away and augmenting the strain. The lines of force increase until their number and intensity become so great that something must happen; that happening is the lightning flash.

Such discharges are direct and not alternating, pulsatory and not oscillating. The heavier charges generate heat so intense that its duration of application, an infinitesimal part of a second, suffices to volatize sap in trees and explode them into slivers, turn wire into vapor and blow the vapor through cloth insulation, fuse metal, and even crush hollow conductors. Humphreys estimates that the energy transformed or dissipated by one discharge is the equivalent of 14,000 horsepower at work continuously for 24 hours. The 44,000 thunderstorms which enliven this earth daily produce 100 flashes a second. The globe is circled in a rain of fire which represents a perpetual transfer of 268 million horsepower, just one by-product of the burning sun. A good telescope reveals countless galactic universes each composed of millions of suns far greater than ours, some of them millions of light years away, and one ceases to worry for fear there will not be power enough to go around. Physics has indeed done its bit to provide the word "infinite" with meaning.

It is rather amazing that with all its power and its frequency, lightning remains as innocuous as it is. Death by thunderbolt happens to only three persons in a million during a year in this country. As a killer lightning is negligible.

The housefly would laugh at it. It is far safer to have a thunderstorm playing around one's head than an automobile around one's feet. Think of what you will, whether it be bathtubs or breadcrumbs or a handful of Germans with a grievance, and they all provide more business for the coroner than lightning. Yet our 400 annual thunderstorm casualties could be reduced by half or three-quarters by the slightest exercise of caution on our part.

Lightning, it must always be remembered, loves the upthrusting, the conspicuous. The electricity in the clouds is always seeking to combine with the electricity in the earth. It is the world's first love-story. When this tendency becomes too strong for the intervening air's resistance to counteract, the discharge takes place. The shorter the distance to be leaped, the greater the chance that it will be leaped, and the oftener. That is why hill summits, trees, steeples, and even lone caddies in fairways, are invitations. Every year some farmer, seeking to save the last dollar's worth of hay, defies a 40-billion-volt cloud with a pitchfork.

Indoors is the best refuge. Modern steel construction is practically lightning-proof. The savagest bolt of lightning can be led off like Mary's lamb on a wisp of copper. The metals are all good conductors, thousands of times better than air. In the play, a lightning-rod gives the discharge a good exit line.

Outdoors can be safe too if one isn't proud. The prone position may be ignominious but it is life insurance. Wet clothes are uncomfortable but they are better conductors than the human body, while dry clothes are poorer. A cave or overhanging bank not too near trees or wire fences affords good shelter. An isolated tree is suicidal, and a pine the worst of the trees, since its deep tap root is so well grounded and offers the least resistance. The oak's wide-spreading root system has an equivalent effect. Mountain peaks stream with

electricity. Artificial respiration, with prevention of chill, may restore even the severely shocked.

The flier shuns the cumulonimbus more on account of the plane-wracking turbulence than because of the lightning danger. His plane is not grounded and yet it may encounter an ionized path at the instant of discharge or even be utilized as a conductor if between cloud and cloud. Most strikes occur at the freezing level or slightly below it, and the hazard is increased by rain or rain and ice. The thundercloud can almost always be seen and, like the bull in a pasture, it is a potential danger which prudence will circumnavigate.

Lightning occurs in snowstorms and then cannot be accounted for by the accepted electrical process of splashing raindrops. It is thought to be due to the electrification caused by the rubbing or collision of solid particles.

It is not an unusual thing to see a thunderstorm born. On a day of light wind and heavy heat when the ground cooks the air and rising columns form, very often a cumulus cloud will swell and darken before one's eyes. The recently fluffy cloud hardens into rounded up-pushing domes and perhaps an adolescent thunder is heard. This signifies that the raindrops have already formed and split. As this process grows, the dark underside of the billowy white crests turns a slaty blue, and the gray fringe of rain can be seen falling. The chances are that this cloud may move away from the conditions that created it, and diminish. But it may grow into an adult storm, taking up moisture in advance of it, precipitating that, and rolling on, a cylinder of air wheeling eastward though with the wheel revolving in reverse motion, up in front.

This is the heat thunderstorm, the "local" thunderstorm of the forecasts. It is usually of short duration and small coverage and is the commoner sort in the more humid sections of our country. It rarely builds up to great violence

and leaves things pretty much as it found them, only wetter.

But when the summer weather map shows a well-defined low heading for the northeast, one may expect excitement. The cyclonic wind circulation permits of greater temperature contrasts. As the cool front advances in a majestic arc, it is spaced by a line of thunderstorms, like a momentous charge of cavalry whose onrolling squadrons, each one a separate sockdologer, may extend from Mississippi to Pennsylvania. These are the memorable occasions, with squall winds up to 70 miles an hour, torrents of rain, perhaps 2, 3, or even 5 inches, and severe incessant lightning.

A great effect requires a great cause. Before notable thunderstorms the heated air must have been nearly saturated with moisture to a far altitude. A sluggish low-pressure system provides these conditions. A winter low will be cloudiest and wettest in its southeast quadrant, but the less intense cyclone of summer, with its higher dewpoint, often has burning clear skies. As the center approaches, however, a veil of cirrostratus cloud mounts, against the south wind, from the northwest. In reality it is a snowcloud, although the ground temperature may be in the 90's. It has winter colors, a gray darkening down to drab blue. It dims the sun, and presently the eye can just make out the ranges of domed cumuli, violet dark and low on the horizon.

The barometer will have been falling slowly, and now it is reaching the end of its long slide. The cumuli lift their ravined slopes and the uniform indigo of falling rain nears. If this curtain remains uniformly dark, a heavy rain is sure.

Lightning can be seen before the cumuli have lifted far. The average thunder is not heard more than 10 miles. The average cyclonic thunderstorm travels at about 25 miles an hour. As the squall line approaches, everything appears to accelerate. The violent turbulence of the massive cumuli be-

comes partly visible as wraiths of vapor materialize and ride like witches to dive into their own cauldron. The heated air in advance of the storm is having its last elemental fling. The torn cloud is forbiddingly black. Descending cold air from the rear pushes out in front, driving dust before it, lowering the temperature 20° in a gasp.

The violence of this ground wind is doubled aloft. The rain, supported by the furious updrafts, begins, largest drops first, and surprisingly cold. The trees turn a vivid green against the dark blue, then vanish. An inferno of wind, rain, half-obscured lightning, half-smothered thunder, engulfs everything. The hours of preparation culminate in one of the great dramatic spectacles of earth. The downpour of a whole winter's day crowds into minutes.

The diminuendo starts fairly soon except in the greatest storms. The wind slackens, boxes the compass. The west lightens. The departing cloud is often of greater splendor than the oncoming. Its immense height, glistening in the sun, is evident now. It may mushroom out or hang in sullen mammatocumulus. Sometimes from this departing pile a final violence of lightning is loosed, leaping the miles from cloud to earth with stunning power.

The thunder causes nothing except consternation. It does not even sour milk. It is no more harmful to a human being than a falling roseleaf. Its one use is to report the nearness of its cause, the thunderbolt. Sound travels about 1/5 mile a second. So, after a flash, count your seconds. The game requires a stoutish heart if the approaching dynamo is powered by an able-bodied storm.

The powerful compression wave, after the atmosphere along an electrical discharge has been expanded by the intense heat, is the cause of thunder. If the bolt has been straight and short, the thunderclap is a crash. When the path has been crooked, differences in distance account for

the rolling and rumbling. The variation is aided by echo from hills. But what causes that last portentous thud so common after bolts that have done business? Perhaps some horizontal stratification of the surface air permits this final massiveness of sound. Air must be stable to convey sound far. An exploding bomb can be heard across the English Channel on a still day, but nobody in England has ever heard a French thunderstorm. The reason is that there would have been no thunderstorm if the air were stable enough to hear sound that far.

The amateur can predict the local thunderstorm with native-astonishing accuracy if he will go to the same trouble that a magician would take to perform a card-trick. The stage properties are a vessel of lukewarm water, a piece of ice, and a thermometer. Put the ice in the water and stir with the thermometer until air begins to "sweat" the chilled surface of the vessel. Then look at the thermometer. The temperature given will be the dewpoint. If this reads below 60° F., even a hot afternoon will not be likely to find moisture enough with which to develop a thunderstorm. If the morning dewpoint is 70° or over, and wind direction corroborates, a thunderstorm is likely. The test can be repeated as the day advances, since the trend is always more important than any single observation.

The professional with his map is in a better position than the mapless amateur to forecast the frontal thunderstorms. Even so, the amateur finds clues everywhere: in the persistent south wind that is laying up heated moisture; in the cumulus clouds which are a signal corps hourly throughout the summer. If they increase toward nightfall, watch out. Stationary growing cumuli menace. But no cumulus cloud however black produces a thunderstorm unless rain is falling, within it or from it. Clouds rising against the surface wind are the certain signal of disequilibrium. The position of the

clouds in the different quadrants is important. It is perfectly possible to have thunderstorm weather and no storm overhead, for thunderstorms are choosy. They pick out paths that will supply them with the most moisture. They love rivers. If an active thundercloud appears due north of you, it will be likely to bypass you, and if due south it is even more likely to.

Hail is a by-product of thunderstorms and belongs exclusively to them. Sleet, the ice pellets of winter, is plain frozen rain. Hail is much fancier. It began with a bit of congealed moisture in the upper glaciated level of the cumulonimbus. It fell below this freezing area and, being cold, froze a thin layer of moisture around it. Then the turbulent updraft rushed it up again to acquire a layer of frost. It fell again, heavier, larger, and the ice-layer about it grew. The juggling updraft repeated this tossing of the ball until it grew too heavy to hold, and down it clattered to earth. Hailstones with twenty-five layers have been counted. It requires an updraft of 60 miles an hour to sustain a hailstone an inch in diameter, and 120 miles for one of 3 inches. Sometimes stones unite and make balls like brickbats. The potential fury of the wind in a cumulus cloud can be imagined. Aircraft, beware.

These violent updrafts occur only in the front portions of a heavy thunderstorm. The towering cumuli may not always be seen from below, but they are there. The cold slaty blue of falling hail is often a visible warning. Western Nebraska and southeastern Wyoming find themselves the hailstorm center of our country, averaging 8 hail days a year, while east of the Mississippi the average is a third of that. Hail losses can be so complete that hail insurance is a commonplace in the two tiers of states west of the Mississippi.

Science is studying lightning now with rotating cameras. The results would have interested Franklin. In streak light-

ning it appears that there are many discharges where the eye sees one. The first stroke is often branched, since it meets the greatest resistance. It leaves an ionized trail for the sequent discharges. No scientist has yet photographed the rare ball lightning, though there are enough authenticated cases of its occurrence to warrant acknowledgment of it. Rocket lightning is supposed to be a discharge so opposed by conditions that it can just sustain itself, and so the movement of the flash terminal appears relatively slow. Beaded lightning is probably an end-on view of irregular portions of the lightning path which remained luminous longer. Sheet, or heat, lightning is the reflection from the cloud illuminated by streak lightning in invisible portions. It is not disembodied stuff but the product of a regular storm below the horizon. In daylight it can be seen as an exquisite tremor of silver sheen passing through the cloud. Storms that produce sheet lightning rarely reach the observer, but the conditions that made them may intensify and bring a storm later in the night.

In an arrived storm sometimes the lightning spends itself in serpents and willowy branches in the higher altitudes. It is beautiful but harmless. Even the thunder sounds hollow. Such storms usually come up with the wind, are more or less impromptu and lacking in intensity.

If a human being were required to pay admission to thunderstorms, they would be admired and marveled at. People go to much trouble and expense to procure and see fireworks on July 4th. They are disappointed if the show has to be postponed because of a display of lightning. They have never been trained to see lightning, or they would welcome a free exhibition of such majesty, originality, and indescribable beauty. It is a curious thing that people will go any distance to a fire; but when the fire comes to them, they pull down the window-shades.

CHAPTER 14

Snow

THE MAHARAJAHS of India, I suppose, do not think of themselves as underprivileged. They use uncut diamonds for paperweights. They are not disturbed by the labor problem. Yet, for all their humid joys, they have never seen it snow. Compared with the poorest Vermont boy they are out of luck.

Snow is one of those simplicities over which scientists pore and calculate and finally tear their hair. They cannot discover how it comes to be. Everybody is aware that snow is frozen vapor, that it comes in two shapes—tabular and columnar—that no two snowflakes yet compared have been found alike. But the genesis of a snowflake is still a mystery. Why does nature prescribe the hexagonal type for snow? Why a flat crystal and not a tiny ball of ice? Is there a connection between the designs of the flakes and the conditions under which they form? How quickly does a flake form? How much space does each individual flake need? It is obvious that this reserved and infinitely delicate crystal cannot have had a jostled birth. Some day science will photograph a cloud of budding flakes in color and discover how beauty comes into being.

The flake we see is oftenest only a sketch for a snowflake. The framework is finished but not the complete crystal. Frost has laid the little white girders in place and the crossbeams suggest the floor that would have been laid in its entirety but for the wind's haste. Snow crystals float for long whiles, as the cirrus clouds show, but even this feathery ice must fall. In the excessive frigidity of the Arctic the minute

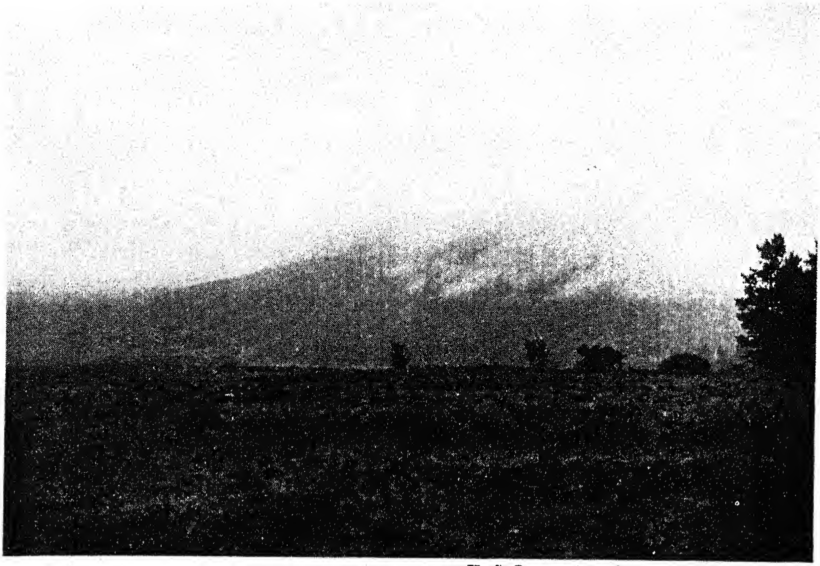
crystals powder down in what must be nearly the original snow. A snowflake of our temperate latitudes is really a community.

People who have never regarded snow carefully should acquaint themselves with the photographs of Mr. Wilson A. Bentley, of Jericho, Vt. His life-hobby has been to perpetuate the most perishable art in the world. Science is revealed wonder, and when it joins hands with art, as in these snowflakes, each exquisite in some new way and each unique, the beholder can do nothing but exclaim inwardly. And this collection of thousands is the merest sample of the beauty that slants across a doorway in one minute of a storm.

Snowflakes in their number, like the astronomer's light years, inconvenience the imagination. They numb the computative faculty. The average rainfall for the United States is a little over 28 inches. Curiously, the average snowfall for the United States (minus Florida and California) is also a little over 28 inches. Thus, since an inch of rain is the equivalent of 10 inches of snow, a tenth of the country's annual precipitation is snow.

Of course to speak of our "average snowfall" is little better than nonsense. Mississippi rarely sees snow in measurable amounts, while much of the North receives from 60 to 100 inches a year. Mountainous Colorado has 200 inches a year, and highland California such quantities that nobody can visualize these snowfalls. Tamarack, Calif., received 884 inches in one winter, or 73⅔ feet. My southern brethren who have never tried to dispose of a 10-inch snowfall with a shovel will have no idea of what I am talking about. Snow must be lifted to be believed.

Much of our country lies in the zone where each large winter storm may be either snow or rain, and is usually both. The moisture-freighting winds come from the ocean that has not cooled so rapidly as the land. As the easterly pull of the



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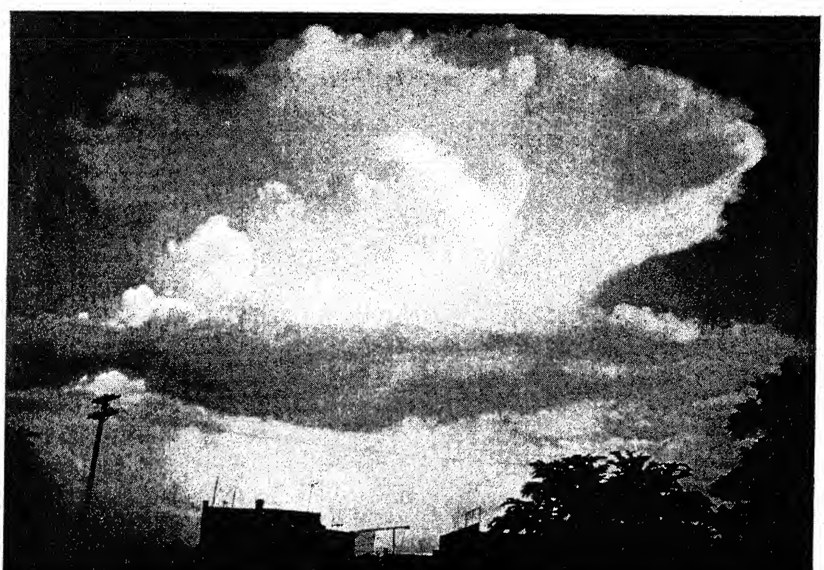

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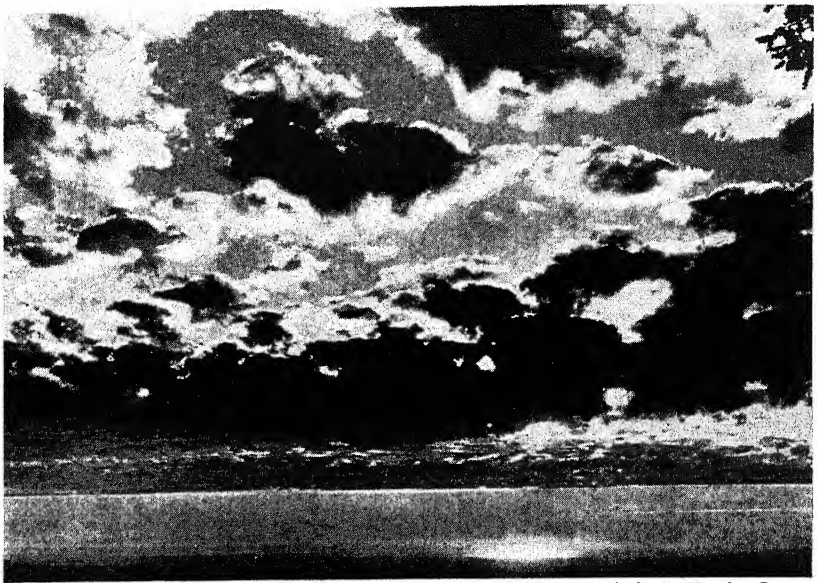

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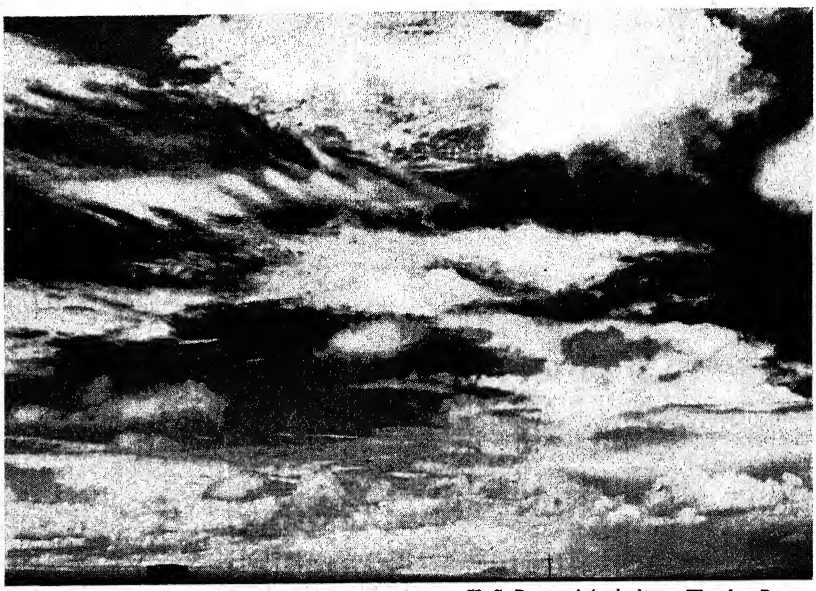

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CUMULUS INTO NIMBUS

wind increases with the nearing of the lower pressure area, this warmer air overruns the colder air and the temperature at the ground starts to rise. Then the disappointing routine performance begins: the snowflakes, which have been small or of moderate size, become irregularly larger. To the snow-lover this is the fateful sign. In a few minutes, with the temperature still below freezing, there will be a heavy fall of large flakes, then a cessation, and sleet with rain shortly following. The rain turns to ice on house and tree, but soon the mercury rises above 32° F. and the slush period arrives. There is only one guarantee of an all-snow snowstorm in the winter months in the zone from southern New England westward: the center of low pressure must pass considerably to the south of the observer. But in March or April when the sea has chilled, there may be heavy falls of snow while the mercury is at or even above freezing on land.

The close watcher has many clues to the severity and probable total snowfall of a storm: the obduracy with which the wind clings to its northeast direction, the steadiness with which it gains force, the snowflake dimensions, the sluggishness of the thermometer, the degree of daylight. A good storybook storm usually begins very leisurely indeed, with small flakes. As the center nears, the snow comes ever faster and the flakes are larger, but not large, and still mixed with flakes of the original size. At the storm's height, if the fall is to be great—that is, over a foot—all sorts of flakes will be whirling by, from large down to snowdust, denoting great activity above, and it will be accumulating at the rate of an inch or even 2 inches an hour. The wind must increase, the barometer fall, the thermometer vary little. The average duration of continuous precipitation in a winter storm is about 8 hours.

The great storms result when two gigantic pressure areas join combat. A stubborn slope of frigid air inhabiting the

northeast is invaded by tropical air from the southwest. The heavy cold air persists, and is helped to persist, by the northeasterly slant of the cyclonic air in that quadrant. But the whole movement of the earth abets the cyclone's approach. It may be swerved to right or left but it must go on or perish.

The compromise arrived at is the upflow of the warm air over the cold and the subsequent condensation. This precipitation liberates more heat and helps to wear away the cold body which has also been drifting at a slower rate from its moorings. A great three-day snowstorm is the answer to the conundrum of what happens when an irresistible force meets an immovable body. Such a struggle occurred over Vanceboro, Maine, and the contestants were so evenly matched that the storm lasted 4 days and left 96 inches of snow on the level. Our impressive storms are really Olympian wrestling-matches in slowly rotating arenas.

Snowstorms that come on the wings of the west wind may be severe but short, and they are unusual in the East, but the heaviest snows of the western states arrive on a north or northwest wind. In the East a snowstorm "announced by all the trumpets of the sky," as Emerson puts it, lasts only a short time. Those that follow a sudden clouding up are of no importance. The great snowstorms bring a culmination to days of confused and cloudy weather. There has to be something in the air to precipitate. The snowstorms that leave on a high west or northwest wind are followed by much colder weather, while those that continue after the wind has calmed down are more often succeeded by warmer weather. It is customary to look for a snow after a period of cold, for the very good reason that the cold front, which by then will have reached the warmer southern states, has inaugurated a wave which produces a cyclone. But it is just as likely that the cold area will shunt this cyclone south of the observer.

Map-watchers soon learn the likely combinations of high and low pressure which bring the theoretically old-fashioned snowstorms to the Atlantic and New England states. Lows passing across the north of the country are no good. Lows originating in Colorado and even Texas are going to be dangerously far to the north by the time they reach New York. The low developing over West Virginia is rare but it grows swiftly in intensity, as it draws in moist Atlantic air immediately, and passes far enough to the south to deliver much snow. The lows coming up the coast will recurve at Hatteras, in which case New England gets a cold but possibly scant storm; or at Long Island, and then the snowfall is almost always heavy. Slow storms yield more snow than swift ones, as a rule. The blocked storm is the record-breaker. If you add a region of quick-rising slopes to the refrigerant latitudes and throw in the Atlantic's moisture, you get the Gaspé Peninsula and the Laurentian region north of the St. Lawrence. There is the snow-lover's heaven. But only heaven knows how much snow falls in those paradisal wastes. Two storms a week, for thirty weeks, and probably never a thaw; it must add up.

Snow is the poet's resource, the farmer's fertilizer, the trafficman's curse, youth's joy—and the airman's problem. At present the conservative flier does not enter a region where ceiling and visibility conditions fail to conform to contact flight minimums as prescribed by the regulations. A flier can see from 2 to 4 miles through very light snow, but even moderate snow cuts down visibility to ½ mile, or thereabouts, and heavy snow from ⅛ mile to a couple of plane lengths. A wet clinging snow can build up to a great weight on a plane. Dry snow, and that granular snow which corresponds to drizzle from stratus clouds, would not so accumulate.

There is one interesting if unimportant datum concerning snow which I have not seen stated. When does snow start to

creak? At freezing and for several degrees below, snow can be crushed without sound. The reason is that, being near the melting point, it flows together progressively when compressed. But when cold, perhaps from 10° to 16° F. above zero, pressure doesn't melt it, and the crystals adjust abruptly, making a noise.

If anyone desires to make a unique motion-picture, let him picture a sound wave lost in a maze of snow. Every cubic yard of snow contains an incalculable number of interstices, tiny air-alleys, minute cul-de-sacs. A sound wave, a pistol crack say, or the snap of a broken stick, may start off loudly and bravely over and through snow. But its energy is sapped by the million little one-way streets of the snow. Snow is nine-tenths air, but that air is so arranged and held in mimic caves and tunnels that the sound wave dies in these countless microeddies, and the aboriginal hush of outer space resumes. The quick ear finds that snow while falling is not quite soundless. But once at rest, the utter silence that it has brought is perhaps its most subtle charm.

CHAPTER 15

Seven Varieties of Fog

IF SNOW is woe to the flier, fog is paralysis. Fog is water evenly distributed through air in minute particles. Squeeze a cubic mile of fog and you might get only a gallon or so of the *aqua pura*, or rather not so *pura*, for each particle has a smaller hygroscopic nucleus at its center. Fog comes on little cat feet, according to Carl Sandburg; but you can kill a cat. You can't kill fog. Even snowstorms cease, but some fogs persist for weeks. It is because fog is so featureless, ungraspable, so mischievous on such small means, and usually so comparatively shallow, that it is irksome in addition to being dangerous. There is only one safe treatment of fog—to avoid it through prediction; and to predict fog one must know the causes of its three main types—radiation fog, advection fog, and precipitation fog.

Fog, fundamentally, is caused by moist air that has been cooled below the dewpoint. That is, fog is a cloud, misplaced. Radiation fog, which is the type that most landsmen see, occurs over surfaces that lose heat sufficiently to lower the temperature of the air above them to the dewpoint. On a clear night the temperatures will fall 20° to 30°. If this is a September night following a warm day, the air has been capable of holding a good deal of moisture. Say that the temperature at 6 P.M is 65° and the dewpoint 45. The spread is 20°. At midnight, the temperature may be 50° and the dewpoint 44, with a spread of 6°. By 3 A.M. the temperature may be 45° and the dewpoint 44, with a spread of only 1°. The air will have become appreciably hazed, and on the ground dew

will have started to condense on the somewhat cooler surfaces where the temperature and the dewpoint coincide. By 6 A.M. the temperature will be 42° and the dewpoint 42 with the condensation, now as fog, reaching up some distance into the air. After sunrise the fog process may continue to increase in height, since there is a tendency to convection of a mild sort which enables the cold surface layer of air to mix with the layers above it. Fog can be seen creeping up the sides of valleys. Presently the sun warmth causes evaporation to begin, the fog also rises, and under ordinary circumstances soon vanishes.

If the spread between temperature and dewpoint amounts to 30° at sunset, radiation fog is unlikely, since it would take unusual cooling to bring the temperature and dewpoint lines together. But with a smaller spread and if the two lines converge, fog is very likely in the longer nights of fall. Of course in winter the temperature falls even faster, but the moisture content of the air is customarily small on a clear winter night. A cloudless sky is essential to a thick fog, since a layer of clouds, even as high as 10,000 feet, can retard the cooling process appreciably. Of course the percentage of cloud coverage is a deciding item.

Radiation fog is born in hollows, valleys, and over wet soils where cooling takes place more rapidly than on heights where the wind mixes air. Dew precedes fog, and fog would always succeed dew if the nights were long enough, but in early and midsummer the sun recommences the heating process before the cooling that has condensed the dew can extend into the upper air. A slight drift of air favors fog formation. If there were no air movement, the fog particles might merely settle. It is probably this settling process that gave rise to the notion that dew falls. Dew does not fall any more than the sweat forming on an ice-pitcher, which of course is dew, can be said to fall. Nobody speaks of frost falling.

Radiation fog can still form with the air movement as fast as 10 miles an hour, but in a wind above 12 to 14 miles it is out of the question. Fog forms earliest when the spread between temperature and dewpoint is least, when the air at the surface has been warm and moist. Fog that forms late clears early. Dry air over the fog layer accelerates the clearing. If the radiation fog drifts over warm water it clears magically, but if over cool water it may persist. In winter, fog may not clear during a day, or even for days.

Advection fog differs from radiation fog in that it depends on wind. For the most part it is caused by a flow of warm moist air over a colder surface, as when the exhalations of the Gulf Stream are carried across the Labrador current. These fogs cover immense areas, are often dense, and may be 3000 feet in depth. The sunshine does not clear them and nocturnal cooling has small effect except to enhance them over land. Only a broad strong shift of wind can clear them away, and this is but temporary. Of course when they intrude upon the land, as in California, the sun's effect tells.

Coastal areas and lake shores with a high temperature contrast provide local advection fogs. They are much less extensive than the great sea fogs caused by the vast current contrasts, although they may be thick and carry to 2000 feet up. The sun over their water areas has small effect but dissipates them on land, and an offshore wind will free coasts from them entirely.

There is a subdivision of the local advection fog caused by sea breezes at places where the water and land temperatures are highly contrasted, and this fog rises little above 1000 feet. It is limited to a few hours and is easily affected by other winds.

Then a steam fog occurs when very cold air overruns warmer water, as can be seen on the Great Lakes when a cold front is passing, and it is common over Arctic waters. It is a

shallow tenuous sort of fog at worst and stops with a rise of air temperature. This patchy fog can occur on any cold night over rivers and lakes when the light wind happens to be nearly saturated. It does not form if the wind is high, and rarely rises over 500 feet.

Finally there is an upslope advection fog occurring when a layer of moist air is borne uphill. The air usually becomes opaque only during the last half of the transport. The wide and continually mounting terrain east of the whole Rocky Mountain system, from Alaska to Mexico, provides upslope fog in autumn, winter, or spring, when the wind blows from an easterly direction. The southeastern slopes of the Appalachians are another making-ground for this sort of fog. Cyclonic conditions control its appearance, but it can be very extensive and the deepest of all fogs, extending upward for a mile and more. The wind-shift rather than the sun dissipates it. The Appalachians, being close to the sea, can fog in at only a slight rise. When the wind mounting these slopes is from the northwest, fog is much rarer, as the air is drier.

Fliers, having information as to conditions aloft, can fly above advection fogs, but with this hazard, that a forced landing through it is always risky. Temperatures in such fog may be 20° F. lower than in the air above it. This makes for stability. There is no way for the colder air to reach up and mix with the warm air. Fog areas have boundary zones of haze. The actual boundary is rather ill-defined and shaggy. The windward side is the safer, but a wind-shift and invasion of drier air can alter the outlines rapidly.

There are two great advection fog kingdoms in our hemisphere. The Grand Banks of Newfoundland might be called the capital of one, and the Aleutian Islands the capital of the other.

Precipitation fog results when rain falls into a saturated layer of colder air. This is oftenest seen in winter when a

warm front begins to overlap the retreating wedge of anticyclonic air. The rain that starts to fall is warmer than the residue of cold air which as yet is not saturated. The rain as it falls evaporates somewhat, adding water particles to the cold air. This evaporation cools the air and tends to increase the temperature contrasts already noted. After the cold air becomes saturated, the continued evaporation causes fog.

Precipitation fog can attain great depth, building up to the clouds and making an obscurity for fliers that may reach up to 12,000 or 15,000 feet. It may blanket much of the eastern coast of North America and is dispelled only by a fundamental wind-shift. Precipitation fog grows slowly, and can clear rapidly. In summer, rain is normally colder than the air into which it falls and a precipitation fog is rare. In winter, low surface temperatures and stratified temperature inversions, bringing warm moisture over cold air layers, occur with nearly every warm front. Unless the wind and turbulence are too great, a precipitation fog is something the aviator can count upon. It is not unusual for a drizzle to bring the cloud down with it.

One sort of fog often impinges on or combines with another. Radiation fog can be carried along by a wind and so assume in part the appearance of an advection fog. Similarly an advection fog can be blown toward a warm front and be intensified by precipitation fog's conditions. The observer will know his terrain and how hospitable, on account of bodies of water, valleys, and elevation, it is to fog-making. He will be sensitive to the trends that lessen visibility and keep an eye on the spread between temperature and the dewpoint. The spread plus wind direction tells much. But, as Kraght points out, the best precaution an airman has against fog is an alternate and fogless airport.

CHAPTER 16

On Ice

If water always froze when it should, that is, with reasonable celerity in temperatures at freezing and under, the aviator's life would be simpler—and longer. But it doesn't. Liquid water droplets can be found floating in a temperature as low as 20° below zero Fahrenheit. And in any cloud with temperatures below freezing there is likely to be this supercooled water, harmless until disturbed, but if so much as joggled it turns into ice instantly. Petterssen reports that in extreme cases this ice may form on aircraft at the rate of a quarter inch a minute. It follows that the larger the raindrops and the greater the turbulence, the more imminent the peril of icing.

In stratified clouds with their weak vertical currents, the water droplets are likely to be of microscopic size. These do not break on impact, and the chance of impact is smaller since they tend to flow around exposed surfaces along with the windstream. Larger drops penetrate the friction layer of air next to the craft's surfaces, and not only on the forward edges of wings and struts but on the horizontal surfaces where it becomes dangerous. De-icing gadgets cannot cope with everything, and until they can, the flier's best course is to avoid the more dangerous situations.

The two most hazardous environments occur in cumulus formations where strong convection keeps large raindrops aloft, and in winter areas of freezing rain. The lofty cumuli, although chiefly summer phenomena, rise into freezing levels.

Their chimneys of up-racing air shower the cold surfaces of the plane with supercooled water, and icing can be extremely rapid. Of course there is always a warmer level below in which the flier can dispose of his ice quickly. But if you add the turbulence of a thundercloud to the loss of lift and other icing changes, you have immediate peril. The lofty but smooth flight over, the detour around, or the rough flight under, the cumulonimbus are all better than the icy way through.

The winter warm front zone provides the other common environment of hazard. Here the layers of cloud are deep, and there are not likely to be melting regions within reach. A high-level flight into a level so cold that most of the moisture is in ice crystals, or at any rate so minute in size as to be safe, is one possible path out. But it may take the flier up to 30,000 feet. Another path is to seek levels of snowfall or of above-freezing rain. Even sleet in itself is not dangerous, but sleet is almost always mixed with rain. This is the area to avoid, or else the flier is soon taking to his parachute. The solution is to stay with the very cold air as long as possible and then seek the warmest level as quickly as possible.

If all warm fronts progressed according to plan, the meteorologist could plot the boundaries with fair accuracy. But each storm is unique. First comes the large formless area where ice is predominant. Then a small area where the snow is wet enough to cake upon the plane. Then a still smaller area of sleet with a mixture of rain. Then a large formless area where water is predominant. Now all these areas are shifting, changing in size and shape with the acceleration or slowing-up of the storm. The freezing line lifts and falls. The result is quandary.

It is more difficult to approach the frontal zone from the cold side. The details of the frontal structure are hard to learn. On nearing the cloud area from the warm air mass,

the flier need only keep below the freezing level to pass at last into the cold air at the level of briefest exposure to icing. If the freezing level is on the ground throughout, all precipitation should be in the form of snow and so without danger.

The fliers' icing problems will be solved by more free-air data and improved mechanical means; but the terrestrial damage from ice will probably continue as long as warm air flows over cold.

Glaze storms wreak much damage every winter in the United States from Minnesota to Georgia, from Maine to Arkansas, wherever a passing warm front gets held up by the retreating cold. In every extensive storm there is usually some section where a little freezing of the rain transpires. But the great damage is caused by the stalemates, when a layer of freezing air stubbornly clings to the surface and yet is not deep enough to turn the rain into sleet before it reaches the earth. Sometimes this condition lingers for several hours, or even days, during which the ice amasses and the subject populations can only look on while wires break, limbs are wrenched from trees, and passersby splinter their legs on pavements. Ice is not slippery. In reality it is fairly sticky stuff. But add heat (with a skate edge, for instance), and it melts sufficiently to become slippery. And if you add water in thin films over inclined sidewalks, it becomes quite unreliable. The property damage of a glaze storm, while enormous, gets repaired. The aesthetic damage to ancient and magnificent trees is permanent. The only return is the crystal glitter when the sun comes out; it is not enough.

CHAPTER 17

Majesty, the Hurricane

In 1938 a hurricane, although far from home and worn with travel, did $300,000,000 damage to part of New England in a few hours. Shorn woodlands, altered coasts, and the memory of the hundreds who perished on that September afternoon, gave meaning to the name of this storm to several million people. They had no more realized what their fellow-Americans of the South had to face the possibility of, every autumn, than the natives of the Gulf coast actually knew of a Dakota blizzard, a Kansas drought, or a California earthquake. Understanding and sympathy do not ordinarily venture far ahead of experience. Twice a year hurricanes hit our southern coasts, on the average, and about once in every three years a hurricane of devastating intensity occurs. One hundred and fifty-two hurricanes have assailed our Southeast in the last 82 years. Between 1885 and 1935, 56 of these tropical disturbances crossed Florida's coastline, and 41 were of hurricane intensity.

The hurricane is the weather's mightiest work. Its Oriental twin is the typhoon. The Pacific breeds these storms faster than the Atlantic. For every hurricane in the West Atlantic there are two typhoons in the Bay of Bengal and *six* in the West Pacific, many of which harass the China Sea. By the paradox which one comes to associate with nature, this marvel of energy originates in the world's most listless region, the doldrums. In this belt of languid airs and sun-stricken ocean, 10 to 15° wide and thousands of miles long, the hot humid air constantly rises, to be spent in thunderstorms. This

featureless region is a huge pan of evaporation. Then suddenly during a few weeks of each year something happens, and a hurricane is born.

Meteorologists have not enough data as yet to be certain of the facts of birth. Since hurricanes do not start closer to the equator than 5° or 6°, it is clear that the deflecting influence of the earth's rotation is required to impart the spiraling motion essential to their genesis. This cannot be felt in the minor areas common to a heat thunderstorm. But if there be an expansion of air over a very large area, caused by an increase of temperature or of vapor density, the return current of compensating cooler air—cooler because descending or because of partial evaporation of rain—may evidence a perceptible spiraling about the inevitable lower pressure at some center. This process, when once begun, grows out of itself until a vast circulating mass of air, nourished by the near-steam of the heated ocean, whirls westward in sympathy with the trend of the trades and is grooved, as it were, by the belt of higher pressure along the north. It travels like a top, its progress hardly measurable at first, while its spin is rapid.

This convectional theory of the hurricane leaves its moment of origin to unexplained chance and does not answer the question as to why the heating of some larger-than-usual area should occur only occasionally. So some meteorologists have built up a countercurrent theory based on their study of the surfaces of separation between two air masses with different temperatures and different movements. This line of discontinuity is a front and the extratropical cyclone is born, according to this theory, from a wave forming on such a front. It is conceivable that an occasional stronger frontal wave crossing the trades collides with the humid convection of the doldrums and starts a sequence of cooling, precipitation, and circulation which, when fed by the richly moist air, becomes a hurricane. Humphreys objects to this mechanical-

eddy hypothesis, because the maximum linear velocity of particles in a whirl caused by the mutual drag between two passing streams of air (such as the trades and doldrums) can never approach the force of hurricane winds since it can only be equal to the relative velocity of the parent streams.

The correct clue will probably be found in the season. West Atlantic hurricanes prosper mainly in September and October, with an occasional one in August and a rare left-over in November. If the frontal theory is right, then the position of the doldrums in relation to the trades at that season may prove something, and the thermal energy generated by the tropical winds and rains might take care of Humphreys' objection. But the frontal theorists have to meet another fact: simultaneous ship observations from an extensive ocean area indicate that when a hurricane is being born, the air is unsettled over thousands of square miles of heated ocean—not along a comparatively narrow line—and that it has no definite center at first, but with the pressure falling over the entire region until conditions focus the decrease at one spot and produce a center.

The tropical cyclone—which is the meteorologists' term for hurricane—differs from the extratropical cyclone (which is our comparatively house-broken North American variety) in more ways than would seem possible to storms of like origin—if the origins do prove alike. The hurricane moves westward during half of its life at least and sometimes for most of it, and not until it nears our coast or when well within the Gulf of Mexico, does it turn north and northeast; our cyclone's paths are always in some easterly direction. The hurricane season is rarely longer than ten or twelve weeks and centers on Labor Day; our cyclones occur in a year-long sequence and reach their greatest intensity in winter. The hurricane path is narrow, sometimes only 50 miles across at the start and not often over 500 miles in maturity; our

cyclone is as wide as the nation from the Gulf of Mexico to Canada. The hurricane has a calm, even clear, center, which is often only 5 or 10 miles across and rarely over 30; the cyclone has no such cloudless center. The hurricane's isobars make circles on the map; the cyclone isobars are egg-shaped, and sometimes trough-like. The hurricane rainfall would average ten times that of the ordinary extratropical cyclone, and it is more evenly distributed around the center. In a hurricane the pressure begins to fall when the winds commence; in a cyclone the fall can commence a day or more ahead of the center. The hurricane never pairs with an anticyclone; our cyclone almost always has one in tow. The hurricane therefore has no cold front or wind-shift line; the cyclone has. Our extratropical cyclone, furthermore, never thinks of wandering down into the tropics; the hurricane not only invades our Temperate Zone, but it suffers a metamorphosis into an extratropical cyclone. This is pure anticlimax, an Emperor become congressman.

As is proper to its imperious dignity, a hurricane gives warning of its stately approach. While acquiring power, its center is almost stationary. When advancing, its forward movement averages about 10 miles an hour until after recurvature. The wind is swiftest on the right-hand side of the center, going with the storm, and may be as high as 75 yards a second. This is the quadrant that mariners shun if they cannot avoid the entire hurricane.

The first sign noticed by an observer in the hurricane's path may be a break in the steadiness of the trade winds, or an increase in the ocean surge, or cirrus clouds which take on especially angry colors at sunset or sunrise. As the center nears, the halo-making cirrostratus deepens and lowers, and then an arc of dense cloud, the body of the hurricane itself, appears on the horizon. Broken clouds are now flying at right angles to the cirrus' path. The light wind comes in puffs, then

gusts, and the first nimbus pelts the watcher with a flying shower.

The showers become dense squalls. Each succeeding pulsation blows with greater power. The wind begins to shriek, the ocean roar is confused and immense, the rain, now torrential, slashes at a world grown gray-dusk. Climaxes of wind whip the bellowing, screaming welter of elements into a terrifying chaos, as if naked force had invaded the earth.

The "eye of the storm" arrives and brings an eerie immunity from onslaught. This is the area of lowest pressure. Two million tons of air-weight are lifted from each square mile of land and sea. The sea level rises 10 feet, adding 9,000,000 pounds of weight to every square mile of sea bottom. No wonder that this last straw laid on the back of some geological flaw sometimes produces an earthquake.

With the center's passing, the wind throws its fiercest force upon the locality, but from the opposite direction. The rain resumes like a cloudburst. The barometer rises swiftly, and the survivors know that each ten minutes of the melee will be less overpowering. People's spirits rise, and when the danger is past, they experience an exaltation which seeks outlet according to the individual's nature and character. In this release there is a strong temptation to unbridled license.

The world's lowest barometric record, 26.35 inches, was reached in the September hurricane that swept the Florida keys in 1935. It is estimated that the wind reached 250 miles an hour in the most furious gusts. Hurricane rainfall is overwhelming. Silver Hill, Jamaica, received 96.5 inches in 4 days. To appreciate so stupefying a deluge is impossible. Since the condensation of moisture releases immense energy, it is not hard to account for the vast windpower of the hurricane so long as it maintains its connection with the evaporating sea.

The average life of a hurricane is about 10 days. One

storm was traced from mid-Atlantic to Texas, whence it curved northeast and closed its career in Siberia at the age of 4 weeks. The Weather Bureau, even with the slim facilities for observation afforded, does an excellent job of warning shore and shipping of the approach of one of these monster storms. The reader will find Ivan Ray Tannehill's book, *Hurricanes*, full of interest and enlightening figures. So grand and fatal and important is the tropical cyclone that history has kept a record of its every occurrence, an honor paid to no other manifestation of our weather.

CHAPTER 18

The Tornado

THE BIRDS, the flowers, and the tornadoes are all busiest in spring. The tornado, however, has the right-of-way. It is the most violent storm this side of the sun. It is so deadly, so terrifying, that the Weather Bureau's policy is not to predict tornadoes, inasmuch as it is impossible to forecast where one may strike and therefore inadvisable to paralyze a community with fright on a mere probability.

Fortunately this parcel of wandering disaster is limited in many ways. It confines itself, with few exceptions, to the central and southeastern states. The Pacific and Rocky Mountain states are immune. It practically never occurs between early summer and the next spring. It usually strikes in the afternoon and never survives the night. Its vortex is seldom more than 150 yards in diameter. Its path may be 30 miles long or 300, but inclines to the shorter distance. It lasts, in any one spot, but a matter of seconds. Yet during those seconds it is the very materialization of destruction.

No instrument has measured the velocity of the upward-spiraling winds in a tornado. Reputable meteorologists estimate it at 500 miles an hour. Straws are driven through boards, the boards through telegraph poles. Pianos are wafted away, and babies deposited unhurt in trees. Houses are exploded by this aerial dynamite, this sudden removal of normal pressure, so completely that the largest piece remaining could be carried away by a couple of men. The vortex roars over a barn like the vacuum cleaner it is, and the building showers outward in all directions. Only underground

shelters are safe from the blind forces curled in this empty whirl of air.

Science has learned much, but not all, about the tornado. It is the dark child of an ordinary cyclone which has an anticyclone crowding in on the northwest and west. It is commonest when the isobars form a V-shaped trough southward or southwestward. The pressure gradient is usually steeper than average, that is, the isobars will be close together on the map.

Over most of our country the temperature and humidity contrasts are greater in the spring. Much colder air overlies the new warmth. In ten out of eleven anticyclone-trailed cyclones, the undersurface of the cold front slopes moderately along the ground. But occasionally this cold slope occurs above the earth's surface and the angle between the two air systems is steeper, since there is no drag by the ground. As the upflowing warm air has a north and east movement, and the down-flowing cold air a south and west movement, a whirl tends to develop. This whirl is entirely in the clouds at first, but condensation liberates heat, increases the spin, drags in air from lower and lower levels until the ground is reached. This action produces the dark pendent funnel-shaped cloud of moisture and dust whirling around the vortex. The whirling wall creates a partition across which the outer air cannot flow into the low pressure within the column. At the top, however, air can flow in and, joining the spin, sustains the diminished pressure below. Air also flows into the lower end of the tube, until it is hermetically sealed by the ground.

A day likely for tornadoes will have been hot and humid. Cumulonimbus clouds brood over the southwest. Sometimes this cumulus spreads aloft in that dark thumb-stippled mammatocumulus oftenest seen after the severest thunderstorms. Rain and hail precede the twister, slackening, as the funnel approaches, for the benefit of photographers. Considering

the comparative rarity of tornadoes, their swiftness of approach, the roar, the blackness, the imminent danger, it is astonishing how many photographers have had cameras handy and the presence of mind to use them. After the pictures have been taken, the tornado rushes away and a deluge of rain falls.

The observer in the tornado zone who has been rendered alert by a tornado-weather forenoon will keep one eye on the black clouds in the southwest for the first sight of the slightly funnel-shaped trunk which may be let down. He will bear in mind certain facts which may aid escape if it is seen. The rate of advance is from 25 to 40 miles an hour. The path is invariably from southwest to northeast. The roaring funnel, nightmarish as its approach is, will not interrupt its course to pursue one personally like a bull around a pasture, and a sprint to the northwest or southeast might be sufficient to save one. If caught indoors, the southwest corner of the cellar is best. The suspense at any rate is short. Darkness intensifies to night blackness. The roar of disintegrating houses increases. For a few seconds pandemonium rides the air . . . rides by, and the danger, except for falling pianos, is over. Lightning resumes. More hail and rain fall, and the rescue work begins.

One showery morning in England, the sky suddenly darkened, wind tore furiously through the treetops, and a tornado-like gust passed within a few yards of where I was standing. It cut off a corner of a stable roof. Hail followed. This immature tornado intensified as it raced on, leveling fences and twisting trees. It blew a small pond out of its bed, and finally shoved an entire train off the track.

Shortly afterward the Channel coast was raided by three waterspouts, marine brothers to the tornado. Two broke against the cliffs, and the other moved inland in modified form and gave Mr. Foster's Gloucester a 9-inch rain. The

well-developed whirlwind at sea creates a waterspout on the same principle as the tornado. Its funnel is hollow because the waterdrops are kept from the center of the vortex by centrifugal force.

As the conical spout touches the surface of the sea, it whirls the water, tearing it into a mist, and the sea itself rises several feet into the partial vacuum of the vortex. But the sea is not drawn up bodily into the cloud, as is proved by the freshness of water precipitated on ships which occasionally pass through the spout. More than one waterspout has been dissipated by firing a cannon at it.

Waterspouts occur along the shore of the eastern United States, usually in conjunction with severe thunderstorms. They have little of the destructive force of the tornado.

As the tornado zone of our country becomes more populous, the spring terror will stalk more malignantly and with greater depredations. It is doubtful that anti-aircraft fire, even if practicable, could dissipate that funnel. Perhaps tornado-raid shelters and afternoon alerts may save human lives. Perhaps a greater knowledge of overhead conditions may enable forecasters to localize predictions with sufficient accuracy to warrant making them. The flier, at any rate, can escape, for this is one danger that is visible in time.

CHAPTER 19

The Barometer

IF A MAN had a friend as seemingly tricky as the barometer, he could shoot him and risk little with a jury. There are no limits to the inconsistencies of this instrument as forecaster, especially if its owner is so inexperienced as to pay attention to the "Stormy . . . Rain . . . Change . . . Fair . . . Very Dry" printed across the faces of the aneroids. While this book was being written two of the wettest storms commenced with the black needle pointing to "Very Dry," and three days of windy sunlight transpired while it slowly crossed "Stormy," "Rain," and "Change." Ananias died before this invention and thus saved his self-esteem.

Yet without barometers the Weather Bureau would go out of business. When people ceased consulting groundhogs and started to consult the barometer, the science of meteorology began. The column of mercury was the first indicator of what the invisible atmosphere was up to. When the telegraph enabled an observer to gauge the barometric pressure simultaneously at many places, large-scale forecasting was born.

How then, it will be asked, could a device apparently so mendacious be adopted for reliable forecasting?

The inconsistency resides not in the movements of the mercury or the black needle, but in the interpretation thereof. The barometer has one simple job, and one only. It registers, moment by moment, the weight of the atmosphere directly above it. When the warm, moist light air of a cyclone invades a locality, the pressure is partially removed, and the mercury column falls. When the cold dry heavy air of an anticyclone

lumbers in, more pressure is applied, and the mercury rises. So, in the rough, a falling barometer came to mean a storm, a rising one fair weather.

This was a generality that glittered. If that were all there was to it, weather officials would have a sinecure. Even the simplest and most straightforward weather is seen to be a compound of many influences, horizontally, vertically, and rotatory. The barometer does not indicate the wind direction, the humidity, the temperature, or turbulence of the air layers. It isn't meant to. It is unfair to revile it for being wrong simply because its manufacturer has printed words on its face. Of course sometimes the words are right. There's the story of the man who bought a barometer on the day of the New England hurricane, and when he reached his home in Connecticut and found the hand pointing to the word "Hurricane" he took the instrument back to the store. On general principles he was justified, anyway. The words do not mean a thing.

Nor does the reading at any given moment mean much either. The *trend* is what counts. The trend, taken in conjunction with all the other signatures of the weather, begins to assume a meaning.

The principle of the mercurial barometer is simple enough. A glass tube, about a yard long and sealed at the top, is filled with mercury and then the open end is temporarily closed while the tube is set in a vertical position in a vessel partly filled with more mercury. When the temporarily closed end is opened, the mercury in the tube sinks a little and comes to rest at a level approximately 30 inches above the level of the mercury in the vessel, leaving a vacuum above the column of mercury in the tube. Thus no atmospheric pressure remains above the mercury in the tube. Since the pressure acts on the mercury in the vessel, the weight of the mercury column above the mercury in the vessel must be equal to the

weight of the air column above the mercury in the vessel. Thus the length of the mercury column shows the variations of the atmospheric pressure by its variations, and a scale placed by the tube supplies the readings.

Before these readings are accurate, however, certain corrections must be made. The length of the column depends somewhat on the temperature of the mercury in the barometer, so readings are corrected for the thermal expansion of the tube, the mercury and the scale, using freezing as standard. The weight of the air column depends somewhat on the local gravity. So a correction is made to obtain the pressure that would be observed if the local gravity equaled the normal gravity at 45°N. Since every barometer has its own individual error, that is corrected, too. And if it is to be used at a certain altitude, a further correction is made for that. In an aneroid, the pressure is balanced not by mercury but by forces of elasticity. Air is partly removed from an airtight metal box which is attached to a frame. When pressure increases, the box is slightly compressed, and a pointer connected with the box swings to the equivalent degree on the scale. The self-recording barometer, the barograph, is an excellent instrument to have because it shows the trend. Its continuous curve doubles the value of the instrument since it reveals what the atmosphere has been doing in the long intervals when the observer was not watching, and continuity is what counts when clues are desired.

Intimacy with the barometer is most quickly attained by annotating the daily graph with a pencil. If the observer had the patience to mark down the time of the appearance of the first cirrus clouds, the first wind-shift after an anticyclonic peak's passing, the start and finish of precipitation, of cold waves, and so forth, he would discover the inordinate diversity of variations in barometric pressure that nature derives from the simple theme of falling barometer, unsettled weather—

rising barometer, clearing. He would notice that the tempo of the change is often a give-away, a rapid fall usually meaning a quick intense disturbance, while a rapid rise would mean a quick clearing to much colder. A slow fall might indicate either an oncoming cyclone of impressive proportions or merely a sluggish movement of the atmosphere. The wind is the forecaster's best collaborator. If the glass falls but the wind remains in a westerly direction, no excitement. A falling glass with an easterly wind bears wet fruit.

Most graphs, particularly through the winter, show rather slow declines and rapid rises. Plateaus of highs are commoner than broad valleys of lows. The novice will be surprised at the oscillations within the trend, with a 6 A.M. maximum and a 4 P.M. minimum. He will also find ripples, especially on cold winter days, marking the passage of air billows above the surface air, just as the passage of waves in shallow water affects the bottom. There are seasonal and regional changes which he will not notice. The storm changes will remain his chief interest.

The natural limits of the barometer's swing at sea level are about 31.00 inches and 29.00 inches. In winter so great a pressure as 31.00 would bring intense cold and complete clearness. It so happens that while this book was being written, occurred the highest and lowest barometer readings at Concord, Mass., during the 50-year period that records have been kept, namely, 31.07 and 28.51. On the December morning of the record low, people who had made what they supposed was a lifelong friend of their barometers, rubbed their eyes and looked again. 28.51 was more extreme than the 29.10 (for Concord) in the 1938 hurricane. In fact such a reading had not been observed in the winter months anywhere in New England. The natural thing to do was to look out the window. Yet no trees were flying by nor was the air filled with barns. During the night, it is true, a heavy rain had fallen, approxi-

mately 3 inches, and the wind had reached 45 miles an hour. But that was no hurricane, no wind that couldn't be duplicated a dozen times a winter.

The reason was, of course, that the isobars were spread over a great expanse of country. If they had been crowded, as in a hurricane, the memory of '38 might have been wiped out by a far more disastrous blow. The return to normal pressure was very slow. For two days the mercury climbed so gradually that observers were startled, each time that they looked at the glass, to find it still far below the ordinary level in great storms. During those days the weather imitated a gusty spell in March.

In Chapter 23 will be found a table of "indications" of the weather that certain tendencies of the barometer forecast. But I must come back to my first statement that the barometer, if taken alone, is something of a practical joker. If read in conjunction with its past, however, it is a miracle of perspicacity, far more sensitive than its owner. With other data of the period, or with the daily weather map to show the general shape of things to come, it becomes a specialist, a sorter-out of possibilities, a guide to the unseen, mirroring the changes in the unfathomed air-sea above with consummate fidelity. Studied for what it is, it becomes the forecaster's third eye, his chief monitor. It takes a lot of knowing to keep up with it.

CHAPTER 20

The Weather Map

THE WEATHER map is to the forecaster what the financial page is to the broker. Each is an over-all picture of the current situation, each gives the changes during the past twenty-four hours, and each is subject to misinterpretation owing to certain forces that have remained invisible. Both map and page are, fundamentally, pressure charts. Both mirror cycles within cycles not yet fully understood. And profit is the motive behind each.

We are all shareholders in the Weather Bureau and receive enormous dividends on the three-cent fee. Petterssen says, "Although the sum total of expenditures for meteorology may be considerable, it is perhaps not out of place to mention that the expense per capita per year is of the order of magnitude of one or two postage stamps."

The truth is that the Weather Bureau, which saves the country hundreds of millions a year and many lives, has never had the funds it needs. The reason is, of course, that thermometers cannot vote and there is no pork in a rain gauge. The coming air age will reveal to the public, and it is hoped to politicians, the requirements of a more generous support. The appropriations for weather services may sometime climb from the per capita cost of a postage stamp to that of a gallon of gas or even one admission to the movies.

The weather map is the chief medium of the forecaster, his crystal ball. Meteorological data flow to it from hundreds of stations, are digested by the forecaster, and then disseminated by all sorts of communication services to the four corners

of the country and the ships at sea. We laymen very coolly accept the *tour de force* represented by the daily forecast, turning up our noses at any error. But the thing has always seemed to me a sort of miracle, like playing a piano concerto with an orchestra, or the ensemble balancing tricks at the circus. This making of the map is a feat of organization capped with artistry. The chief forecaster has to perform daily for millions without a prompter and without applause, and he is always conscious of the enormous responsibility. For his few words mean salvage or ruin, safety or death. If his act were staged on Broadway with a $3.30 top, he would be famous. The routine can be condensed as follows:

At 7.15, morning and evening, 75th meridian time, observers at 300 first-order and 450 second-order stations in our country and cooperators in Canada, Mexico, the West Indies, and ships at sea, note the sky, classify the clouds, read the barometer, mark the direction and velocity of the wind, measure the precipitation, record the temperatures, calculate the humidity, and jot down the occasional phenomena, such as fog, thunderstorms, halos. No observer dare be sleepy, for he must condense these data into cipher, each message consisting of groups of figures, and put it on the wire by 7.30. At the district forecast center they are translated by an expert and entered on a chart by the chart man. The translating is under way by 7.40 and is usually stopped by 9.15 so that the forecaster can complete his analysis and prepare to begin his forecasting by 9.30. The forecasts are being dictated within a few minutes and are wired to the Weather Bureau stations in the states for which they have been made, and copies are furnished to the newspapers.

No names of places are printed on the base map for the United States. A mere circle identifies a location, and the chart man must be able to enter the data instantly for each station. He writes in, by symbols or figures, the state of the

weather, the amount of cloudiness, rain, snow; the direction and force of wind; the temperature and dewpoint; the barometric pressure reduced to the value it would have at sea level; the pressure tendency and amount of change in the last three hours; the amount of precipitation; and the miscellaneous data.

Meanwhile the forecaster has been going back to the maps of 6 or 12 hours before to refresh his knowledge of their fronts and air masses. Presently translation of the messages and the chart-marking has progressed far enough for the forecaster to start drawing in the isobars—the lines connecting stations of equal pressure. These are now expressed in millibars instead of inches and are drawn for 3 millibar intervals (approximately .09 of an inch). To anyone raised on tenths of inches, the millibar is a forbidding example of scientific simplification, being 1/1000 of the pressure that would be exerted per unit area by a column of mercury 29.531 inches high at 32° F. in latitude 45° and expressing a force of 1000 dynes per cubic centimeter. Fortunately conversion tables are available.

The forecaster next draws in the fronts, the cold ones in blue, the warm in red, and the occluded fronts in purple. He classifies the air masses, marking the continental polar air which is colder than the surface over which it is moving cPk, for example (k for *kalt*). A cold front is located by considering surface temperature discontinuities, pressure tendencies, surface wind discontinuities, dewpoint discontinuities, the type of cloud, and the character of precipitation. Warm fronts give more trouble. Pressure decreases are slower than the increases with a cold front, but the cloud sequence helps and a high dewpoint is characteristic of maritime air imported by the warm sector.

While these data are being put down, the forecaster is already making up his mind as to the projection of the *lows*,

the centers of low pressure, and the *highs*, the apexes of high pressure, for on their direction and rate of travel depend all the states of weather he must predict. The art of forecasting is to have as little art in it as possible, to base conclusions on the *musts* of observed facts rather than on assumptions. For instance, it is a sound rule to consider that lows and highs will move with the speed and acceleration that they have had in the preceding 12 hours. But it is an equally sound rule that a low moving toward a stationary high will be retarded and curve northward until it becomes parallel to the isobars of the high. The forecaster also knows that the speed of a low or high is inversely proportional to the curvature of its pressure profile. That is, a low or high center that is circular, a pronounced curvature, will move slowly, while flatter systems will have widely varying speeds for which other rules must be found. Very oblong centers move along the longest symmetry axis. Experience will have salted away in the forecaster's memory any number of such fundamental generalizations. But for a concrete prediction, he must call on measurement, that is, on comparison with the preceding maps expressed in number.

By now upper-air data will have been noted on accessory charts. He can discover changes in wind circulation as compared with the sea-level map, and note the displacement of lows and highs as provided by radiosonde figures on the 6000, 10,000, and 14,000-foot levels. In the free air the wind obligingly blows very nearly parallel to the isobars, and changes in the pressure field can be estimated.

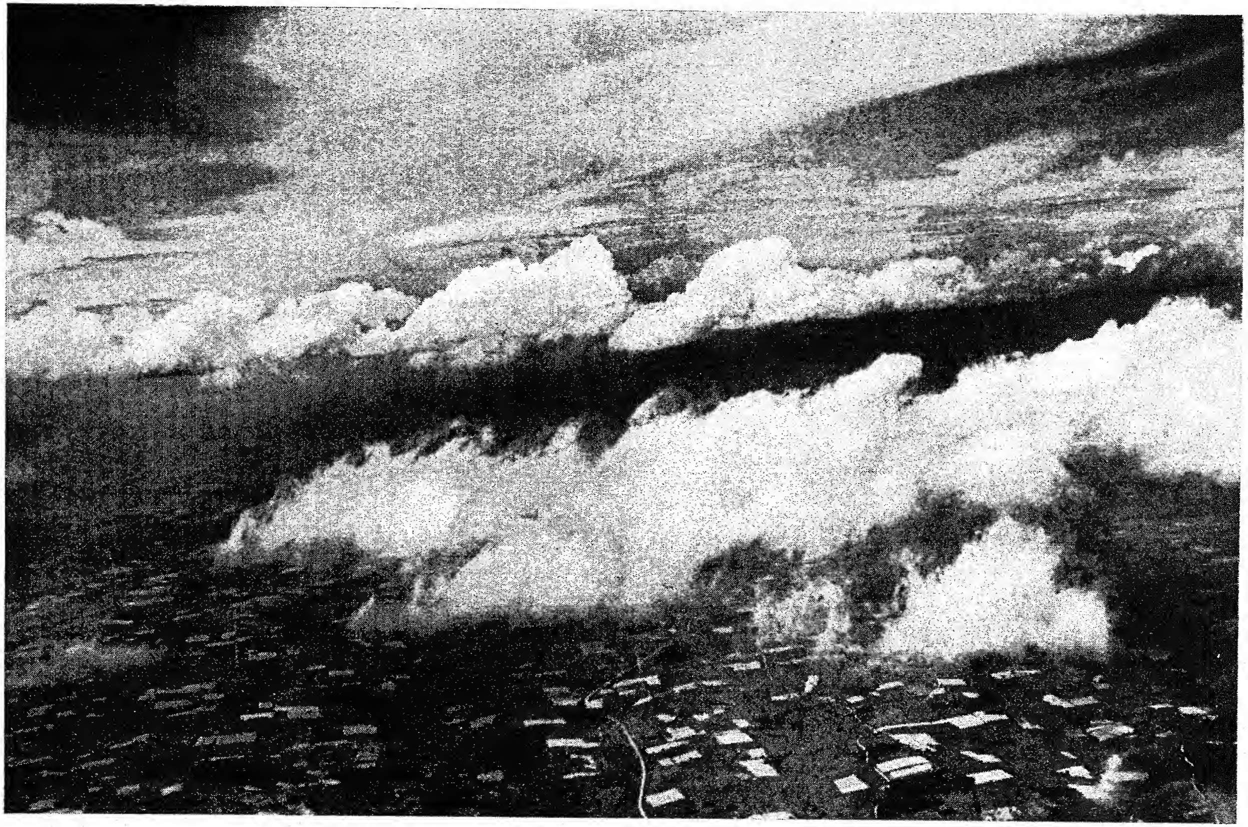
The forecaster has three auxiliary charts of great value. The isentropic chart, a map of the air unaffected by surface heating and cooling, aids in identifying the air from one map to the next. The cross-section chart pictures vertical distributions. The pressure-change chart, with isallobars (lines drawn through points showing an equal amount of change in baro-

metric pressure within the last specified period) indicates how the lows and highs are moving and changing in structure. From these charts the forecaster can get a good view of his pressure systems and determine which are deepening (increasing) or filling (decreasing).

Up to this point the forecaster has been brooding over the welter of data at his disposal. But time is getting short. Late reports from Alaska, northern Canada, and Greenland are being charted while he engages in some mathematical computations as to the geostrophic winds, the free air winds above friction levels which blow between isobars as river-waters between banks. In Washington the forecast district comprises 16 states and the District of Columbia. The decoding and plotting of data from pilot balloons, radiosondes, and planes begins earlier than the 7.30 translation of code reports from land stations. About 90 minutes suffices for the map drawing.

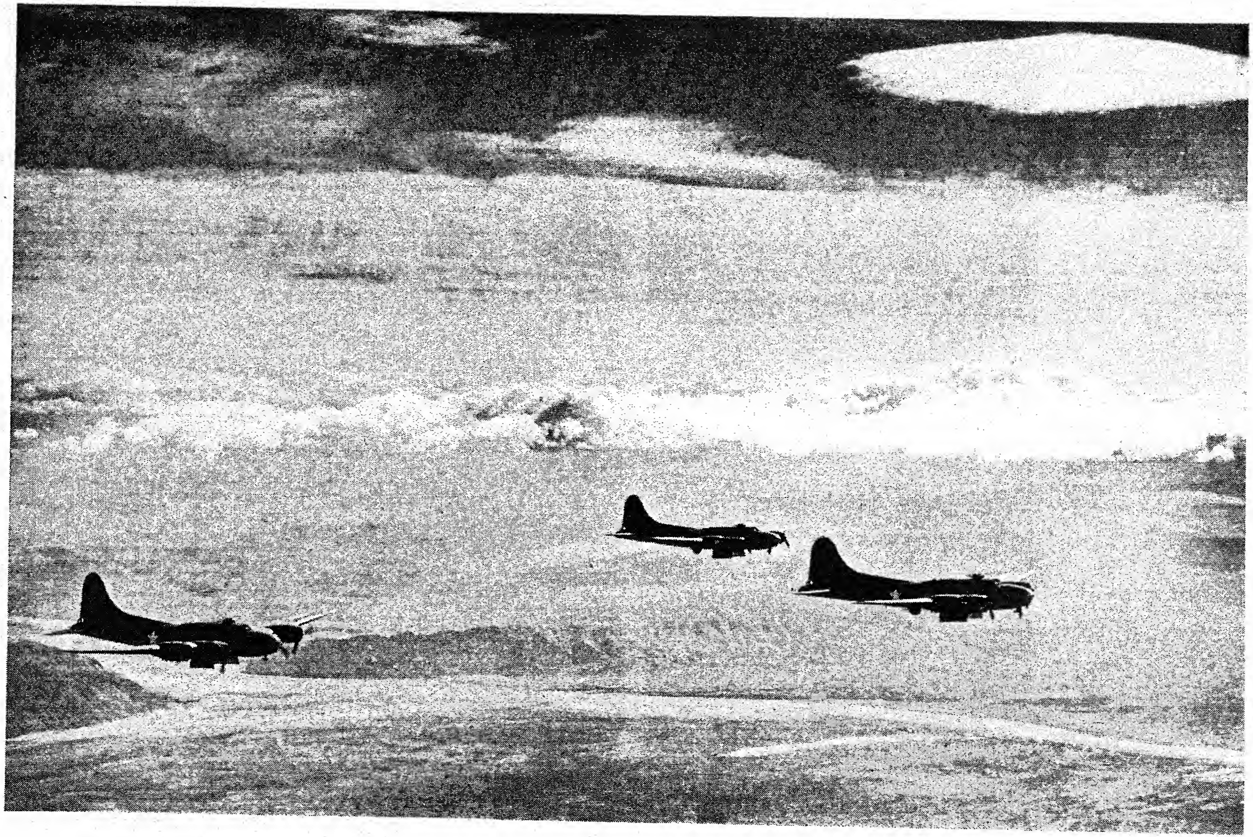
The forecaster, with everything now before him, formulates and dictates his predictions in 15 to 20 minutes. The fateful words are in the public's hands soon after. Presently citizens are taking the weather's own verification of the forecast for granted, if it is correct, and if an error occurs, they are exclaiming, "Gosh, anybody'd know better 'n that." The citizen is merely saying that he can pit his intellect unaided against a thousand or so observers, the latest instruments, skilled scientists who have devoted years to the interpretation of the most intricately fluid medium known, and beat them. And so he can, a few times out of a hundred for his particular place of residence. But the Bureau is right 85 times out of 100 for whole territories.

The foregoing abstract and abridged account of the forecaster's workout is cold and colorless as compared with the actuality. In the novel *Storm*, Mr. Stewart's forecaster names his heroines, the low-pressure areas. It is a natural thing to do. The weather map is a daily chapter in an exciting serial.



American Airlines, Inc.

CIRROSTRATUS, ALTOSTRATUS, CUMULUS



Boeing Aircraft Company

CIRRUS, ALTOSTRATUS, CUMULUS

True, the characters are short-lived, although anyone interested can follow them up on their global tours. But, like some casual train acquaintances, they can be exceedingly engrossing for the few days it takes to ride across the country. Each one is different. Some shed benefits, others destruction. After some experience, the observer establishes a norm of pressure-area behavior in his mind and then waits to have it confirmed or deviated from.

He knows that the larger and better formed a disturbance is, the easier it will be to anticipate its movements and development. When the map goes hazy with undeveloped areas or systems of sluggish movement, the challenge is flung. He watches the troughs of low pressure for certain characteristics. A narrow trough will move more slowly than a wide one, and storm centers will develop at its extremes. When the northern end moves eastward faster than the southern, conditions in the south and southwest stay unsettled and a storm will form southwest of the high that follows. When the southern end moves faster, settled weather appears. When the trough is wide, an extensive storm will probably develop, particularly if the temperatures between the highs are high.

When a high covers the southeast and a cold-wave high the northwest, a storm develops quickly in the southwest with general precipitation because of the squeeze play. If a storm forming in the southwest is forced to the left of the normal track, another storm will develop in the southwest immediately and become a certain producer of precipitation. Storms developing in the southwest and moving normally are quickly followed by clearing.

Often a low moves into the northeast only to find its exit held up by high pressure over the ocean. Owing to the supply of moisture it does not fill quickly and causes high winds throughout the northeast section of the country for days.

Storms starting in the northwest and moving southeastward (a favored pattern in winter) do not gather great intensity until they begin to recurve to the northward. At the time of recurving they move slowly and the prediction of clearing becomes difficult.

Marked changes in temperature between the southeast and northwest quadrants imply an increase in the storm's intensity. Small temperature contrasts do not indicate a further development of the disturbance. Abnormally high temperatures northwest of a storm indicate that it will either remain stationary or even retrograde. A low, east of the Rockies, increases in intensity as it moves to the left of its normal path. Storms with isobars closely crowded on the west and northwest move slowly and to the east or southeast, and the precipitation and high winds are maintained unusually long in the northern and western quadrants. Storms with isobars crowded in the south and southeast quadrants move rapidly northeastward and the weather quickly clears after the passage of the center.

The rate of a storm's passage across the country depends largely upon the strength of the winds aloft. The velocity of the winds is determined by the intensity of the low-pressure system. Neither the rate nor the intensity remain uniform for any protracted period.

Inheritance plays a great part in the action of a storm. A low from the high cool dry region of Colorado and a low from the Gulf-fed moist warm region of Texas may show the same pressure distribution, the same size, formation, and apparent energy. But their effect on the country east of the Mississippi will be totally different. The Texas low, not having to recurve, will move speedily, give heavy precipitation, and in winter carry the above-freezing line far north. The Colorado low will be retarded by curving, cannot deliver as much precipitation, and will therefore fall behind the Texas low

in intensity, since the latent heat freed by condensation is an aid to energy. In winter it will not drag the freezing line so far north, unless it is pushed to the left of its normal path.

Many storms leave a legacy of conditions which permit of a secondary formation. These developments take place in the occlusions of the trough of the primary low and occur over the eastern part of the country. Much depends on the pressure over Bermuda. If it is low, the secondary center will pass northeastward off the Atlantic coast. If high, the storm is shunted to the left of this path and crosses the southern Appalachians to water the Middle and North Atlantic States. If pushed very far to the left, the low crosses the Great Lakes with abnormally low pressure, sometimes with the barometer reaching the middle 28's. This is hurricane pressure but the storm lacks rainpower and high, but not hurricane, winds prevail.

A well-developed low passing up the Atlantic coast to the Canadian northeast is usually balanced by a marked high over the Hudson Bay region and is a signal for colder than normal weather to follow throughout the East. In the case of two lows at the ends of a trough, the secondary, in the south portion, almost always develops into the main storm. Sometimes it seems as if the lows join, but careful observation of 4-hour pressure changes shows that they don't. The primary fills, the secondary deepens.

Forecasting of the winds depends on the path, speed, and intensity of the lows and highs. Temperature predictions depend chiefly on the accuracy of the wind forecast. It is an axiom that unless a well-marked low passes over an area, no great change in temperature will follow. Forecasters use key stations to check temperature predictions. Washington, D.C., in a period of northwest wind can expect a 7.30 A.M. temperature corresponding to the 7.30 A.M. recording at Cincinnati

the morning before and the 7.30 P.M. recording at Pittsburgh the evening before.

Forecasting precipitation is more difficult than for wind or temperature. Lows are apt to be wet if they have a well-developed warm sector; also if there is a localized 12-hour pressure fall or wind circulation in the southern part of a trough. Rain or snow (not obviously due to orographic effects) back of the cold front shows the persistence of warm moist air from the south aloft. In an intense low this warm rain-making air can be carried all the way around to the north of the center, and precipitation continues.

Highs share the responsibility for our weather, of course, but are less obviously dramatic except as cold-wave producers. When a great high builds up over the Mackenzie Valley its center usually remains over Saskatchewan and Manitoba with a southern extension reaching to Texas. The cold area then pivots eastward, its rear still in Canada, and a low develops rapidly in the southwest with general rains and snows over all the country to the southeast.

A circular high over the Mississippi Valley is almost always followed by a rapid development of even a slight low over Texas with swiftly increasing intensity as it races northeastward. The New York skier wishing for snow will note a high over the northwest promising cold, and a low over the southwest promising precipitation, and he will hope for their simultaneous approach, insuring snow. But nine times out of ten the high will apparently say "After you" to the low, with a bedraggled snow-and-rain combination following. Storms have the right-of-way. Only a persistent high over northeast Canada will assure continuous frigidity during the passage of the low.

The list of generalizations could be continued indefinitely. The novice at chess, seeing the number of possible moves, is surprised by the regularity of his defeats, but presently fore-

sees his opponent's habitual sequences and systems. And so with the weather map. If the novice looks in the "Monthly Weather Review," Volume 70, Number 10, for October, 1942, he will find a chart of the tracks of October anticyclones, and a chart of October cyclones. There are 9 tracks for the highs and 8 for the lows, and no two of these 17 tracks coincide. Even the two highs that started closest together ended thousands of miles apart, in Mexico and off Nova Scotia. No two of the lows even began close together. Aside from the very broad generalization that the trend was from west to east, it would seem impossible to predict where one of these features would be centered on the morrow. Yet the course of every high and low was foreseen by the forecasters for one or two periods ahead with all but complete accuracy.

Rigorous mathematics is playing an ever greater part in forecasting. Methods for evaluating the velocity and acceleration of pressure formations—the cyclones, anticyclones, troughs, wedges, and fronts—are being announced and applied. The resultant equations look more formidable to the non-mathematician than any old-style analysis of the weather, but the proof is in the prediction. The ideal which the future meteorological Einsteins hope to attain is to be shut up in a room with a pad, pencil, and telegraphic reports, and to emerge with calculated solutions for every puzzle on the map.

No doubt this way progress lies. The atmosphere can be counted upon to obey the rules, at least, and when the kinematical methods have been deduced, simplified, and practiced in conjunction with world-wide observations, the first sure step to long-range forecasts will have been taken.

Meanwhile the amateur has his weather map and the personal equation. He has every morning a bird's-eye view of the continent's weather. He has a staff of faithful servants to report to him the very facts he wanted to know. He has an

interest presented to him daily in serial form, an interest with some practical aspects, and one which draws on the inexhaustible forces of nature to make it exciting. It is one on which governments spend more and more of their energies that he may be satisfied. Such an interest is likely to last. Other enthusiasts may give up book-collecting or private yachts, but once a weather-lover always a weather-lover, and the heyday is not yet.

CHAPTER 21

On Climate Worries

CLIMATE is weather history. After a man has undergone the weather in one locality continuously for thirty years, he can boast of having sampled its climate. After a few centuries in the same spot, his remarks on the climate should be listened to with some respect provided he refers to his records rather than his memory. But to command the attention of scientists, he must produce evidence covering at least one precession of the equinoxes, a cycle occurring every 26,000 years, and preferably an ice age or two. Science has counted the annual layers of silt in lakes deposited 28,000 years ago. It has studied tree rings, and found out about climatic surges from the succession of plant types in peat bogs. It has learned climatic data from fossil bones and glacier marks and the ancient utensils of migrating man. It is not interested in the diaries of dyspeptics who decide on cloudy mornings that the climate is changing.

It is a curious thing that mankind, a race of hopefuls, should so continually express its opinion that the climate isn't what it used to be. In common belief, the climate is rapidly changing, and always for the worse. No generation has ever taken an intelligent stand on the matter and said, "See here, this can't be. If our great-great-grandfathers found the climate pretty awful, and our great-grandfathers knew that it had deteriorated still further, by now it would be completely intolerable."

The funny thing is that the complainers are very nearly right. As mentioned earlier, the earth's current climate is

among the most ungenial, violent, and restless that our planet has ever experienced. But it is getting better. The ice-caps are melting, the mountains wearing down, the volcanic eruptions becoming less effusive. If the people who write down their disappointment about the climate in diaries will wait only a few million years, the climate *will* have changed. One geologic minute and geniality will return. Those who can't wait will have to accept the fact that the only sudden change they can hope for could come through some tremendous volcanic ash-spreading eruption. And that change will also be for the worse.

The latest findings by those who have made a lifework of investigating climates, while mentioning many factors leading to change, narrow the major causes down to two: variations in the level of the continents and volcanic activity. Sun spots, the eccentricity of the earth's orbit, the ecliptic's obliquity, variations in solar distance, possible changes in the composition of the atmosphere, all fail to stand up under examination as compelling factors of drastic change. But the elevation of a continent is easy to accept as a cause, even if it had not been proved that the cold ages coincided with the mountain-building ages.

Even relatively small changes can have large effects. The climate of the United States would be Mediterranean if the Rockies had risen crosswise along the Canadian border. The climate would be Siberian if our northern states and Canada had a higher elevation. A high would predominate, as in Greenland, and the lows would cross far enough south to cause nothing but snowfall. Add enough volcanic dust to diminish the solar radiation by a few degrees and our continent would be subjected to year-long ice and snow. Enough of that and one has an ice age.

So it is not deemed necessary any more to go out into the cosmos for climatic explanations. The earth has made her

own climates to a large extent. The long-range changes are easier to account for than the current ebb and flow within small limits. These rhythm periods embarrass observers by their copious variety. Two or three cycles might have explained everything; but more than fifty cycles, varying from a few days to two centuries in length, have been "discovered." Their complexity has postponed proving anything.

The Department of Agriculture's publication for 1941, *Climate and Man*, contains fascinating pages on the ebb and flow of climate. The 9th century was very wet, the 10th and 11th centuries warm and dry. The Arctic ice-cap is thought to have disappeared completely. Greenland was settled in 984 and not abandoned until 1410. The first half of the 13th century was a period of great storminess. Glaciers in Europe, and undoubtedly America, retreated between 1640 and 1770, and then advanced until the middle of the 19th century. Since then they have retreated back to 16th-century positions. The last century has had higher summer temperatures than the 18th. In the last hundred years the first half of the time has shown a trend to cooler and through the last half a distinct trend to warmer. The winters our fathers remembered actually were, as a rule, more consistently colder and snowier, and are, in the main, at present briefer and warmer. But with each year local records are being broken. Some region or other records more consecutive zero days than ever have been known, or a greater depth of snow in one storm, or a higher wind velocity.

Climate really comes in layers. There is a fundamental layer with a change no swifter than the rise or fall of the continents, a change immeasurably slow. Superimposed on that epochal transition are the abrupt plunges into colder climates caused by voluminous clouds of volcanic dust which cut off enough of the solar heat to induce conditions which are self-perpetuating for long periods. On top of this come

the smaller cycles of solar variation due to sun spots, the influence of carbon dioxide variations, differences in the land's covering, and the other genuine but comparatively slight influences that occasion the swings in climate that Methuselah might have observed. Thus there are climates within climates, each with a tempo of its own, climaxes of its own which may or may not correspond with climaxes of the others. If you will imagine a baby held in the arms of a temperamental nurse who is seated on a rocking-horse which is being carried on a merry-go-round which is in a building shaken at times by earthquakes which occur in the bosom of our rotating planet, you have a picture of the complexity of climate in the variety of motive influences on the baby. Whenever the child is shifted by the temperamental nurse, he thinks the climate is changing. He is oblivious to the far greater and steadier movements.

The surprising thing is not that the climate is stable, but the range of weather within the climatic frame. Diaries of observant men summarize the winters of some of Philadelphia's early years as follows:

1697: long, stormy and severely cold.
1714: very mild after the 15th of January.
1725: mild.
1741: intensely cold.
1742: one of the coldest since the settlement of the country.
1750: mild.
1756: very mild. First snow as late as the 18th of March.
1764: Delaware frozen completely over in one night.
1779: very mild, trees in blossom in February.
1780: the whole winter intensely cold. Ice 3 feet thick.

Presumably the winters not mentioned were average and unspectacular. Of the ten described, exactly half were "old-fashioned," while the other half doubtless proved to people with defective memories that the climate had gone to pieces.

Those who are disappointed at finding the climate so rugged and enduring can always change it for another. Koeppen has classified the world's climates and finds eleven types, with several subdivisions. The connoisseur can reach most of them from New York by plane in a few hours:

1. Tropical-rain-forest climate: Brazil or parts of Central America.
2. Tropical savannah climate: southern Florida.
3. Steppes: Alberta and Saskatchewan.
4. Desert: parts of our Southwest and California.
5. Warm climate with dry winter: interior of Mexico and Central America.
6. Warm climate with dry summer: California.
7. Humid temperate climate: our central, southern, and Atlantic states.
8. Cold climate with moist winter: central, eastern, and northeast Canada.
9. Cold climate with dry winter: northern Canada.
10. Tundra climate: northernmost Canada.
11. Ice climate: Greenland and the polar ice-cap regions.

One climate flows into another. People can live in the carboniferous or the glacial period simply by moving about. Everybody can be suited. A card of inquiry to the Weather Bureau will bring directions as to where to go. Yet, having gone there, having found the desired climate where the authorities said it would be and functioning perfectly, these people will undoubtedly write home complaining that their new climate is already changing.

CHAPTER 22

The Weather as Companion

IN THIS age of questionnaires, when the Government wants to know the color of my eyes, and strangers inquire about my beliefs and finances, it is strange that nobody has as yet investigated my stand on the weather. Nobody has mailed me a form to be filled in asking:

Are you a weather-lover?

If so, why?

List advantages and disadvantages resulting from this mania.

Do you foresee a future for the weather?

This lack of curiosity is curious in itself. Every other human concern has its amateur organizations. But who ever heard of a Woman's Weather Society? Weather has never had its Izaak Walton. Nobody has put up a statue to a meteorologist. Who knows the names of the weather chiefs on whom falls, day after day and year after year, the responsibility for saving lives and property? The weather clearly offers no road to fame or even fortune.

Your true weather-lover, however, has never thought of compensations other than a run of interesting weather and a few accurate instruments. He is happy while looking, watching, measuring, observing. If he has been accepted by the Weather Bureau as a voluntary observer and entrusted with some instruments, he is overjoyed at having to rise at strange hours to observe them, jot down his readings in

triplicate, compute averages, and mail in his results on time. His report helps to supply a comprehensive view of the weather from all over the country, since there are many hundreds of him, and to his pleasure, he adds the feeling of being of use.

But why is it a pleasure to be anchored at home by a rain gauge and some thermometers? Certain people like to amass money, others first editions, and others statistics. The weather-lover is a statistician of sorts. He keeps a diary in code. Certain figures could thrill him to the center of his being. —91° F. That would be a new world's record for cold. 138° F., a new one for heat. But even to beat his own local record is some satisfaction.

The real satisfactions go deeper than that, however, for records are few and far between. He lives with beauty of two sorts—the physical beauty of nature in its freest aspects of wind and cloud, and the meaningful beauty of natural law. He is always secretly hoping that some greater gorgeousness of power may transpire from new atmospheric conjunctions. He understands why the Book of Job is full of weather: it is artist stuff. He is a compound of scientist and solitary, simple man and poet, with a wild acre or two in his heart, as Thoreau had. He laughs at people who disesteem his hobby, since they are funny in their ignorance of the simplest details of atmospheric conduct. They remind him of Tweedledee's reply to Alice when she said it might rain. "It may, if it chooses."

The weather-lover finds his horizons widening. Meteorology is about to become a public service hardly second to the telephone. The professional forecaster will have nobody but himself to blame for inaccuracy when communications are perfected not only from around the earth but from above it. The amateur, with the global map at his disposal, will have a wider sphere for enjoyment.

Yet he is happy now. It is a strange thing, but verifiable, that weather-lovers are among the happiest of men. There is something freeing in knowledge, and their knowledge is of cosmic things. To the farmer, the fisherman, the pioneer, the weather has always been a silent partner, a partner with whom they cannot argue but whose ways they may learn and profit by. The weather-lover is better off than these; he has no living at stake. All is enjoyment, even the extremes which drown the sailor and ruin the farmer overnight. The responsibility belongs otherwhere. Perhaps this lack of responsibility for the discomforts and disasters brought by his unruly interest is the crowning, if not often considered, factor in this enjoyment. Whatever happens, it is nobody's fault. The weather does not have to be legislated about; it is not one of the lapses of democracy.

Another charm of being a weather-lover is that this interest, unlike tennis, bridge, or politics, is dependent upon nobody else. One never has to hunt up a fourth to enjoy a thunderstorm. If this sound anti-social, then so is thinking, which also can be enjoyed alone. The weather-lover has learned not to button-hole others and beg them to share in his enthusiasm. The human race bridles especially at two things. It does not care to hear about one's hobbies or to be converted to one's religion. It protects itself from stupid people who read themselves into others, one of the subtlest but stupidest of errors.

Only for professionals is weather a full-time occupation; the amateur comes back to it only intermittently. It is like dining, delightful but not continuous; yet for the real weather-lover it is as important. The outdoorsman is unhappy without access to sky and wind. To step out into the weather is to be liberated from the man-made. The atmosphere is tameless, free, and full of peril, like the ocean. It is greater

than all the oceans. It is the medium of the future. So the weather-lover, although thinking that his pleasure was self-indulgence, has been pursuing a very practical interest all the while, in spite of himself.

CHAPTER 23

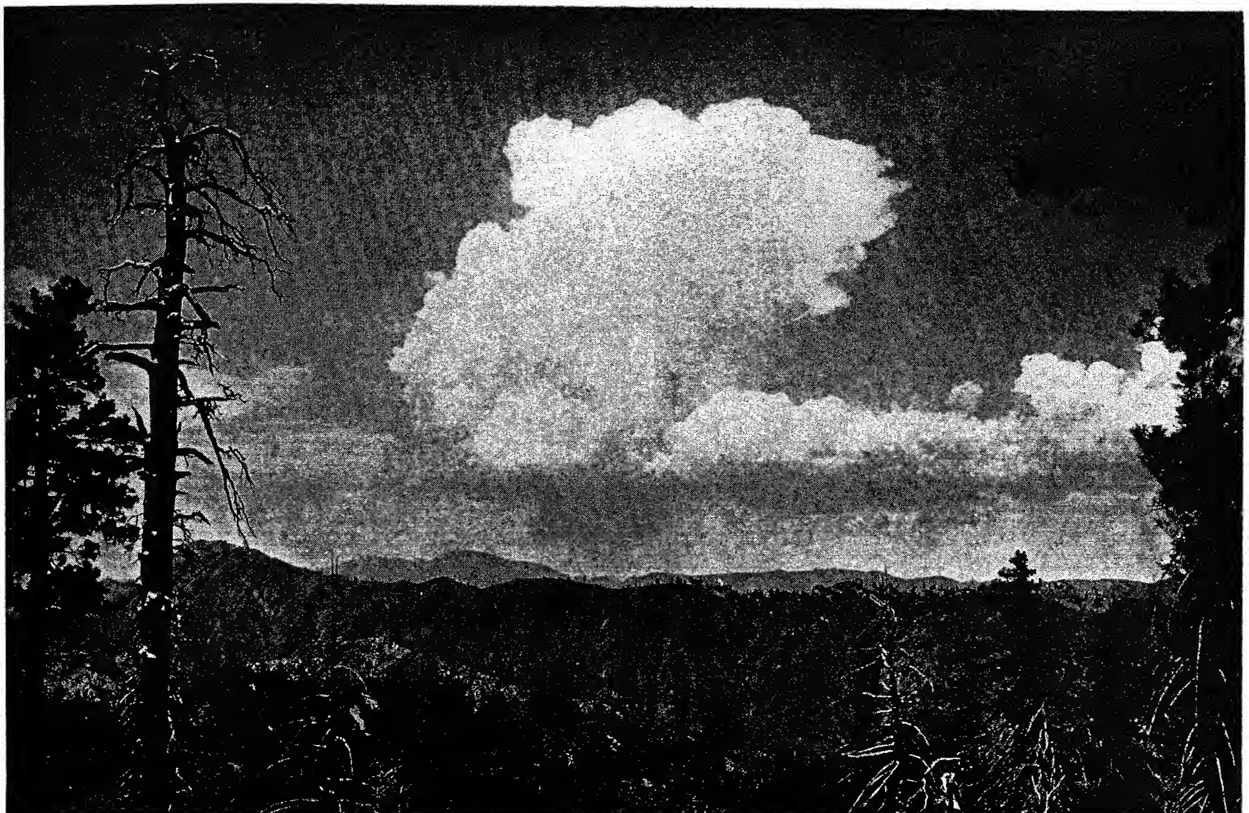
On Weatherlore

EVERY man, in the end, must be his own weather prophet. The necessity of knowing what the weather is going to do comes usually when one is away from professional predictions, and in places where these predictions have to be modified to suit the locality. There is no substitute for seeing, and it is unwise to take the word about today's weather from somebody who died a thousand years ago. That is what proverbs are—observations of the past fashioned for some special locality, and not exportable.

Some of these observations are so broad that they can be true for anywhere. In Matthew XVI, 2, 3, we have Jesus telling the Pharisees, "When it is evening, ye say, It will be fair weather: for the sky is red. And in the morning, It will be foul weather to day: for the sky is red and lowring." Yet there is even a catch in that word red. There are many reds, and more stormy ones than fair.

And so with other of the better crystallizations. They all need footnotes. Much of the folklore is not so much interested in forecasting as in asking the season to be itself. The farmers distrusted a warm March. But what farmers? Not Florida's. And about a green Christmas filling the graveyard. Where was the graveyard? Not in southern California.

The weather proverb is done. Transportation killed it. It is a strange thing, though, to see how slowly people give up the sayings that were moonshine at best. The February 2nd groundhog lunacy. The St. Swithin's lunacy. The tilt of the



U. S. Dept. of Agriculture, Weather Bureau

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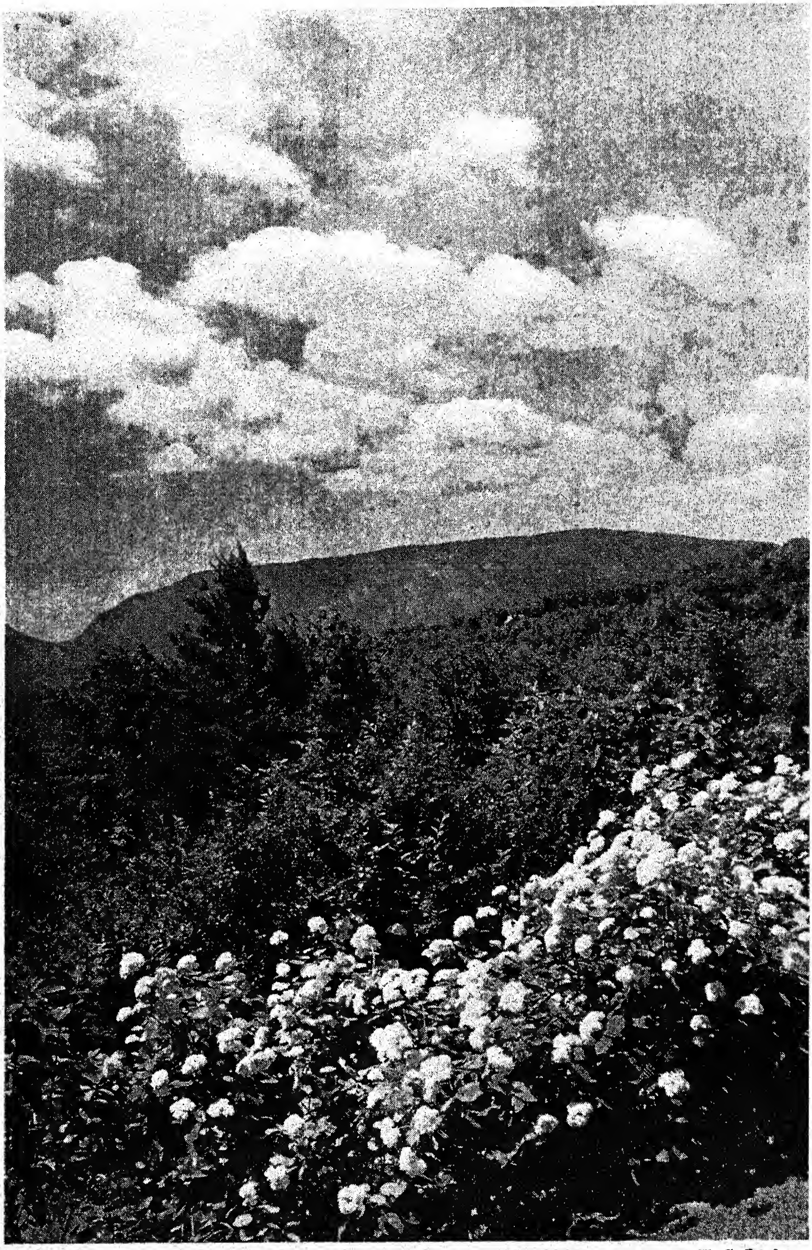

H. S. Latham

CLEAR-WEATHER CUMULUS

moon lunacy. Newspapers still dutifully comment on the March-lion-lamb theory in the spring and list the length of fur on squirrels in the fall. They wouldn't insert the same old hocus-pocus year after year unless there was a call for it. Many people believe things which the slightest resort to mere counting would disprove.

In fact it can almost be said that there are no fool proof weather signs. It can even rain from a cloudless sky. However, there are a few score generalizations which are sound yet subject to change. The Weather Bureau permits itself to print wind and barometer "indications" in the following table. Yet any observer will note the exceptions to these indications as occurring plentifully enough to make them extremely risky guides unless one is equally aware of the conditions that condition them.

Wind direction	*Barometer reduced to sea level*	*Character of weather indicated*
SW. to NW.	30.10 to 30.20 and steady	Fair, with slight temperature changes for 1 or 2 days.
SW. to NW.	30.10 to 30.20 and rising rapidly	Fair, followed within 2 days by rain.
SW. to NW.	30.20 and above and stationary	Continued fair, with no decided temperature change.
SW. to NW.	30.20 and above and falling slowly	Slowly rising temperature and fair for 2 days.
S. to SE.	30.10 to 30.20 and falling slowly	Rain within 24 hrs.
S. to SE.	30.10 to 30.20 and falling rapidly	Wind increasing in force, with rain within 12 to 24 hrs.
SE. to NE.	30.10 to 30.20 and falling slowly	Rain in 12 to 18 hrs.
SE. to NE.	30.10 to 30.20 and falling rapidly	Increasing wind, and rain within 12 hrs.

Continued on page 130

Wind direction	*Barometer reduced to sea level*	*Character of weather indicated*
E. to NE.	30.10 and above and falling slowly	In summer, with light winds, rain may not fall for several days. In winter, rain within 24 hrs.
E. to NW.	30.10 and above and falling rapidly	In summer, rain probable within 12 to 24 hrs. In winter, rain or snow, with increasing winds, will often set in when the barometer begins to fall and the wind sets in from the NE.
SE. to NE.	30.00 or below and falling rapidly	Rain, with high wind, followed within 36 hrs. by clearing and in winter by colder.
SE. to NE.	30.00 or below and falling slowly	Rain will continue 1 to 2 days.
S. to SW.	30.00 or below and rising slowly	Clearing within a few hours, and fair for several days.
S. to E.	29.80 or below and falling rapidly	Severe storm imminent, followed within 24 hrs. by clearing, and in winter by colder.
E. to N.	29.80 or below and falling rapidly	Severe northeast gale and heavy precipitation; in winter, heavy snow, followed by a cold wave.
Going to W.	29.80 or below and rising rapidly	Clearing and colder.

Prof. E. B. Garriott, who was chief forecaster for the Weather Bureau when he compiled that list, need not have stopped there. The permutations and combinations of wind vane and pressure column mount high in number.

Forecasting the weather is very much like playing a hand of contract. Aces are good cards, but a dandy ace (such as a cloudless sky) can be trumped by a 2-spot of east wind. It is the combination that counts, and never the single card. But just as there are rules in bridge that hold good for normal

circumstances, so are there weather probabilities that can be relied on if no adverse signs counteract. I propose to list a few such assurances and the reader will say, "Why, of course!" because they are obvious.

One can look for continued fair weather when:

A gentle wind blows from the west, northwest, or a little south of west.
The wind blows down ravines gently after nightfall.
The sun sets in a cloudless sky, and the tints incline toward the red or yellow.
The sun sets like a ball of fire (continued warm and dry).
The moon rises clear with the wind in a westerly point.
The sun rises out of a mildly gray horizon into the clear.
The summer fog breaks early and clouds rise on the mountains.
There is moderate dew or frost.
The temperature is normal for the season, or colder than normal, other signs being right.
The barometer is steady or slowly rising.
Cumulus clouds decrease after mid-afternoon.
Clouds generally tend to decrease.
The sky has greenish tints near the northern horizon (colder).
Midday snow-flurries occur on a north wind (colder).
The barometer's trend, the wind's direction, the clouds' changes, and the temperature's action are the four aces. To insure fair weather all four must be properly accounted for.

Look for a change toward unsettled weather when:

The westerly wind suddenly drops or shifts to south or east.
Cirrus clouds appear, increase, and merge into cirrostratus.
Summer cumulus darken and lower as the afternoon proceeds.
Wind continues to blow up ravines after nightfall.
The sun sets in fine-textured clouds or cloudbank with hazy edges, sometimes a livid color.
The evening temperature remains much above normal.
Clouds gather about mountain-tops.
Few stars are visible and those are indistinct.
A halo or corona appears and remains.
There have been three white frosts.
Clouds move in two directions at different levels.

Look for a change toward clearing when:

The wind shifts into a westerly quarter.
The temperature falls.
Clouds rise, lighten perceptibly, or break in conjunction with the shift to west wind.
The barometer rises.
Precipitation fog follows the cessation of an easterly wind before the shift to west is apparent.
Raindrops grow smaller after the wind-shift.
Snowflakes drive less busily, float lazily down, or thin out conspicuously.
Seams appear in the clouds.
Lightning and thunder occur to the eastward.

The ability to sense accurately the exact moment when the weights are shifted and the change to clearing commences requires sensitive observation. The storm cycle usually moves in an orderly fashion, but when its tempo changes, and blocking occurs, the foregoing signs—except the shift of wind to the west—are often negatived.

Rain (or snow) will fall:

Within a few minutes after the arch of the thundercloud is seen moving toward one.
Within half an hour, or thereabouts, after the winter sky has become uniform in color that is perceptibly denser.
From 12 to 48 hours after the first cirrus clouds are seen, depending upon the speed with which they deepen into cirrostratus.
From 2 to 8 hours after the sun or moon has vanished in the cocoon of cirrostratus (perhaps).
Every little while from cumuli showerclouds sailing on a south wind in the passing of a summer low.
For a short while from a thundercloud rising on a west wind.
For an hour or more from a thundercloud rising against a south or southeast wind.
For 8 to 12 hours continuously in an easterly storm, a shorter time in summer than in winter, and shorter on a southeast wind than a northeast or east wind. Averages mislead. The expectancy,

however, should not exceed 10 hours unless complications set in. The so-called three-day storm involves a day of increasing easterly wind with clouding up and perhaps a preliminary spit of rain or half an inch of snow, then the onset of precipitation for perhaps 12 hours, a second 12 hours of precipitation fog, or drizzle, a wind-shift and gradual clearing for 12 hours or more.

The temperature will fall when:

The evening sky is free of cloud.
The wind is in a westerly or northerly direction.
The mercury remains at the same level during the sunny hours.
The wind backs from north of east in a storm—the fall will be gradual.
The wind veers from the southwest—the fall is likely to be sudden.
A snowstorm begins. The fall may be only a degree or two and last for only a few minutes or an hour.
A cloudy day clears at sunset.
Snow-flurries are seen, even if they do not reach the earth.
The north sky shows green and the clouds look hard.
The barometer rises, in winter. A summer rise, followed by clearing, may bring warmer weather.

The temperature will rise when:

The wind shifts from a west or northerly direction. When the wind backs into the south, the temperature rises faster than when it veers into the east.
The barometer falls, though a summer fall may indicate an easterly storm which brings cooler weather than does summer clearness.
The morning is free from clouds on any day that is not ushering in an anticyclone.
A thunderstorm is brewing.
A snowstorm has got under way unless the wind is already backing into the north when that shift counteracts the natural warming-up caused by the approach of a low-pressure center.
The sun sets like a ball of fire at which one can easily look.

"The Compleat Weatherer" has never been written and probably never will be, for the reliable indications applica-

ble to any one spot are so multitudinous and blend so gradually into one another that the tome containing them would be qualified and footnoted beyond practicality. And it would never suffice for even the adjoining county. Each man has his own weather, in reality, depending upon his penetration, his pleasure of it, and his ability to observe without ceasing.

Bibliography

The titles that follow would make a good start for a weather library. In the main they are of durable works. Two essentials for anyone who wants to keep up with the weather are the daily weather map (Map C, 19 x 24 inches) costing $3.60 a year, and the *Monthly Weather Review* at $2 a year. The files of the *Review* are a golden lode of interest and information. Another Government publication is *Climate and Man,* A Department of Agriculture Yearbook, for 1941. It contains 1222 pages, costs $1.75, and contains articles by some of our leading meteorologists, including C. G. Rossby. Summaries of weather for each state make this a good reference book as well. From time to time, officials of the Weather Bureau have written pamphlets of great interest, such as *Weather Forecasting*, by George S. Bliss. This Bulletin costs 10 cents. There are dozens of titles, and a price list may be had on request of Superintendent of Documents, United States Government Printing Office, Washington, D. C. The publications mentioned above may be bought from the same source, by check or money order.

Physics of the Air, by W. J. Humphreys, C.E., Ph.D. 3rd edition, 1940. $6.00. 676 pp. This standard work is comprehensive and repaying even to readers who skip the mathematics. Published by McGraw-Hill Book Co., Inc. All of Dr. Humphreys' books are worth owning because of their accuracy and scope. "Ways of the Weather," "Weather Proverbs and Paradoxes," "Rain Making and Other Weather Vagaries," "Fogs and Clouds," "Weather Rambles," "Snow Crystals" (with Wilson A. Bentley, the Vermont authority).

Introduction to Meteorology, by Sverre Petterssen, Ph.D. McGraw-Hill Book Co., Inc., New York, 1941. 236 pp. $2.50. A clear, concise, and basic meteorology for beginners. It in-

cludes an interesting summary of the history of meteorology. Its 142 charts, maps, and tables are an exposition in themselves. Dr. Petterssen's *Weather Analysis and Forecasting*, McGraw-Hill Book Co. (330 W. 42nd St., N. Y. C.) is an advanced study, growing highly technical, but even the beginner can dig into it with profit.

Synoptic and Aeronautical Meteorology, by Horace Robert Byers, Sc.D. McGraw-Hill Book Co., 1937. 279 pp. $3.50. Another introductory treatment. It devotes more attention to phases of weather of special interest to fliers and airways meteorologists. While somewhat technical, as all such books have to be, it is a model of clarity and economical use of the English language.

Manual of Meteorology, 4 vols., by Sir Napier Shaw. The Macmillan Co., New York, 1931–1936. No book that is not republished weekly can have everything. That said, one can add that this work is probably the classic of reference.

Hurricanes, Their Nature and History, by I. R. Tannehill. Princeton University Press, Princeton, N. J., 1938. This is at once an introduction to the nature and methods of the hurricane and a history of the famous ones. Extremely interesting.

Meteorology for Ship and Aircraft Operation, by Peter Kraght, Senior Meteorologist American Airlines. Cornell Maritime Press, 1942, 373 pp. 3.00. This is a textbook written to be understood by airmen by a forecaster who had to be right. Its 155 illustrations would teach meteorology to a child.

Why the Weather, by Charles Franklin Brooks. Harcourt Brace and Co., New York, 1924. Dr. Brooks is Director of the Blue Hill Meteorological Observatory, Harvard University, and this book skims the interesting data from his long experience. It seems slight compared with formal works but it is filled with sidelights on the weather that escape other books.

Weather, by E. E. Free and Travis Hoke. Robert M. McBride and Co., 1928. The authors admit that their work is "not logical

but psychological" and it treats in a very entertaining and educating way subjects which people had asked them about. This weather book has a breeze running through it.

Storm, by George R. Stewart. Random House, 1941. A fascinating novel, as original as *Robinson Crusoe* was in its time. Maria, the heroine, lives out her meteorological life as a great storm should, with drastic effects on some of the people she meets.

Weather literature is like the iceberg—only a ninth of it emerges above the surface of publication in technical papers, and these largely in German and the Scandinavian languages. Our own Weather Bureau and the Massachusetts Institute of Technology, to mention only two pioneering institutions, have probably taken over the leadership in meteorological investigation.

Some Terms Useful to Know

Adiabatic. The word applied in the science of thermodynamics to a process during which no heat is communicated to or withdrawn from the body or system concerned. Adiabatic changes of atmospheric temperature are those that occur only in consequence of compression or expansion accompanying an increase or a decrease of atmospheric pressure. Such changes are also described as dynamic heating and cooling.

Advection. The process of transfer by horizontal motion, particularly applied to the transfer of heat by horizontal motion of the air. The transfer of heat from low to high latitudes is the most obvious example of advection.

Aerology. The study of the free atmosphere throughout its vertical extent, as distinguished from investigations confined to the layer of the atmosphere adjacent to the earth's surface.

Air mass. An extensive body of air within which the conditions of temperature and moisture in a horizontal plane are essentially uniform.

Anticyclone. An area of high barometric pressure and its attendant system of winds, outward-flowing in a clockwise order.

Back. Of the wind, to shift in a counter-clockwise direction; the opposite of veer, occurring in the northern hemisphere when a cyclone center is passing to the south of the observer.

Buys Ballot's law. In the northern hemisphere, if you face the wind the atmospheric pressure decreases toward your right and increases toward your left, and thus indicates the direction of the centers of cyclones and anticyclones.

Center of action. Any one of several large areas of high and low barometric pressure, changing little in location, and per-

sisting through a season or a year, such as the Icelandic or Aleutian lows, the Siberian winter high. Changes in the intensity and positions of these pressure systems are associated with widespread weather changes.

Centigrade. The thermometric scale on which 0° denotes the temperature of melting ice (they used to call it freezing, and it corresponds to 32° F.) and 100° the temperature of boiling water, both under standard atmospheric pressures.

Col. A neck of relatively low pressure between two anticyclones; also called a saddle.

Cold front. The discontinuity at the forward edge of an advancing cold air mass which is displacing warmer air in its path.

Convection. The upward or downward movement, mechanically or thermally produced, of a limited portion of the atmosphere. Convection causes, among other things, the formation of cumulus clouds.

Convergence. The condition that exists when the distribution of winds within a given area is such that there is a net horizontal inflow of air into the area. The removal of the resulting excess is accomplished by an upward movement of air; areas of convergent winds are regions favorable to the occurrence of precipitation.

Cyclone. An area of low barometric pressure with its attendant system of winds, inward-flowing in a counter-clockwise order. North of the tropics the cyclones are called extratropical, better known as barometric depressions, lows, disturbances.

Deepening. Decreasing pressure in the center of a cyclone.

Dewpoint. The temperature at which (under ordinary conditions) condensation begins in a cooling mass of air. It varies with the specific humidity. The dewpoint is a conservative air-mass property.

Divergence. The condition that exists when the distribution of winds within a given area is such that there is a net horizontal flow of air outward from the region. The resulting deficit is compensated by a downward movement of air from aloft; areas of divergence are unfavorable to the occurrence of precipitation.

Dry adiabatic lapse rate. A rate of decrease of temperature with height approximately equal to 1° C. per 100 meters (1.8° F. per 328 ft.). This is close to the rate at which an ascending body of unsaturated air will cool due to adiabatic expansion.

Filling. The occurrence of increasing pressure in the center of a cyclone. Filling is the opposite of deepening.

Front. A surface of discontinuity between two juxtaposed currents of air possessing different densities or, more simply, the boundary between two different air masses.

Gradient. Change of value of a meteorological element per unit of distance, such as the horizontal gradient of pressure, the vertical gradient of temperature, the latter now called the *lapse rate.*

Humidity. The degree to which the air is charged with water vapor. *Absolute humidity* expresses the weight of water vapor per unit volume of air; *relative humidity* is the ratio of the actual vapor pressure to the vapor pressure corresponding to saturation at the prevailing temperature, or simply the percentage of saturation; *specific humidity* expresses the mass of water vapor contained in a unit mass of moist air.

Hydrometeor. A generic term for weather phenomena such as rain, cloud, fog, etc., which mostly depend upon modification of the water vapor in the atmosphere.

Inclination of the wind. The angle which the wind direction makes with the direction of the isobar at the place of observation. Over the ocean the angle is usually between 20° and 30°

Insolation. Solar radiation as received by the earth; also, the rate of delivery of the same, per unit of horizontal surface.

Instability. A state in which the vertical distribution of temperature is such that an air particle, if given either an upward or downward impulse, will tend to move away with increasing speed from its original level.

Inversion. An abbreviation for inversion of the vertical gradient of temperature. Ordinarily the temperature of the air lowers

with increasing altitude, but when it grows warmer with altitude an inversion is said to occur.

Isallobar. A line drawn through places or points showing an equal amount of change in barometric pressure within a specified period.

Isobar. A line on a chart drawn through places or points having the same barometric pressure.

Isotherm. A line on a chart drawn through places or points having equal temperatures.

Lapse rate. The rate of decrease of temperature in the atmosphere with height.

Monsoon. A wind that reverses its direction with the season, blowing more or less steadily from the interior of a continent toward the sea in winter and in the opposite direction in the summer.

Occluded front. The front that is formed when and where the cold front overtakes the warm front of a cyclone. The front marks the position of an upper trough of warm air, originally from the warm sector, which has been forced aloft by the action of the converging cold and warm fronts.

Potential temperature. The temperature that a specimen of air would assume if brought adiabatically to a standard pressure, now usually selected as 1000 millibars.

Ridge. A relatively narrow extension of an anticyclone or high-pressure area as shown on a weather chart.

Saturation. The condition that exists in the atmosphere when the partial pressure exerted by the water vapor present is equal to the maximum vapor pressure possible at the prevailing temperature.

Secondary. A small area of low pressure on the border of a large or primary one. The secondary may develop into a vigorous cyclone while the primary center disappears.

Stability. A state in which the vertical distribution of temperature is such that an air particle will resist displacement from its level.

Subsidence. The word used to denote a slow downward motion of the air over a large area. Subsidence accompanies diverg-

ence in the horizontal motion of the lower layers of the atmosphere.

Synoptic chart. A chart, such as the weather map, which shows the distribution of meteorological conditions over an area at a given moment.

Tropopause. The point in the atmosphere at which the fall of temperature with increasing height abruptly ceases. This point marks the base of the *stratosphere.*

Troposphere. The lower region of the atmosphere from the ground to the tropopause, in which the average condition is typified by a more or less regular decrease of temperature with increasing altitude.

Trough. An elongated area of low pressure. A *V-shaped depression* is a trough of low pressure bounded, on the weather map, by V-shaped isobars.

Warm front. The discontinuity at the forward edge of an advancing current of relatively warm air which is displacing a retreating colder air mass.

Warm sector. The area bounded by the cold and warm fronts of a cyclone.

Wave disturbance. A localized deformation of a front, which travels along the front as a wave-shaped formation, and which generally develops into a well-marked cyclone.

(Terms taken or adapted from the Weather Bureau's *Glossary of Meteorological Terms*)

Beaufort Scale of Wind Force with Specifications

Beaufort Number	*Miles Per Hour*	*General Description*	*Specifications*
0	0	calm	smoke rises vertically
1	1–3	light air	wind direction shown by smoke drift but not by vanes
2	4–7	slight breeze	wind felt on face, leaves rustle, ordinary vane moved by wind
3	8–12	gentle breeze	leaves and twigs in constant motion, wind extends light flag
4	13–16	moderate breeze	dust, loose paper, branches moved
5	17–22	fresh breeze	small trees in leaf begin to sway, crested little waves are made
6	23–27	strong breeze	large branches in motion, whistling in telegraph wires
7	28–34	moderate gale	whole trees in motion, walking affected
8	35–41	fresh gale	twigs broken off trees, walking impeded
9	42–48	strong gale	slight structural damage to houses, signs broken
10	49–56	whole gale	trees uprooted, considerable damage to houses
11	57–67	storm	widespread damage; rarely experienced
12	68 & up	hurricane	excessive damage

Some Extremes of Weather

TEMPERATURES (Fahrenheit)

World's coldest: —90.4°, Verkhoyansk, Siberia, Feb. 5 and 7, 1892.
World's hottest: 136°, Azizia, Libya, Sept. 13, 1922.
Our coldest: —78°, Fort Yukon, Alaska, Jan. 14, 1934.
—66°, Riverside Ranger Station, Wyo., Feb. 9, 1933.
Our hottest: 134°, Greenland Ranch, Death Valley, Calif., July 10, 1913.

PRECIPITATION (inches)

World's wettest: Average annual rainfall, 426. Cherrapunji, India. 241 in one month—Aug., 1841—Cherrapunji. 46 in 24 hours, Baguio, Luzon, July 14–15, 1911.
Our wettest: 23.22, New Smyrna, Fla., in 24 hours, Oct. 10–11, 1924. 150.73 (highest local average annual rainfall), Wynoochee Oxbow, Wash. based on 13-year record).
Wettest state: Louisiana, average annual rainfall 55.11.
Our driest: Annual average 1.35, Greenland Ranch, Calif. Total fall of only 3.93 at Bagdad, Calif. for 5 years, 1909–13.
Driest state: Nevada, average annual rainfall 8.81.
Our snowiest: 884, Tamarack, Calif., winter of 1906–7.
60, Giant Forest, Calif., in one day.
42, Angola, N. Y., in 2 days.
54, The Dalles, Ore., in 3 days.
96, Vanceboro, Maine, in 4 days.
Largest hailstone, 1½ lbs., Potter, Neb., July 6, 1928. Larger stones reported have proved to be conglomerates of several stones fused.
Most destructive storm on record: The New England hurricane, Sept. 1938.
Greatest wind velocity: A gust of 231 miles per hour at Mt. Washington.

Lowest pressure: 26.35 inches, Sept. 2, 1935, Florida Keys (world's record).

Longest path of extratropical cyclone recorded: origin, Havre, Mont., Feb. 23, 1925, traced around globe and past starting point to Gulf of St. Lawrence, March 23. Time, one month; distance traveled by center, 21,379 statute miles.

Some Useful Equivalents

1 meter = 39.37 inches = 3.2808 ft.
1 foot = .30480 meter.
1 kilometer = .62137 mile.
1 mile = 1.609347 kilometer.
Freezing: 32° F. = 0° Cent.
Boiling: 212° F. = 100° Cent.

To convert F. to Cent. substract 32 and multiply by $\frac{5}{9}$

$$C = (F.—32)\frac{5}{9} \quad \text{or} \quad F. = 32 + \frac{9}{5}\,C.$$

Meteorologists use a 3rd scale, *absolute* (A) where the freezing is at 273° and the boiling point at 373°. That is, the absolute scale differs from the Centigrade temperature by the constant 273. This is to avoid negative signs, and for any given pressure the density of the air is inversely proportional to the absolute temperature.

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